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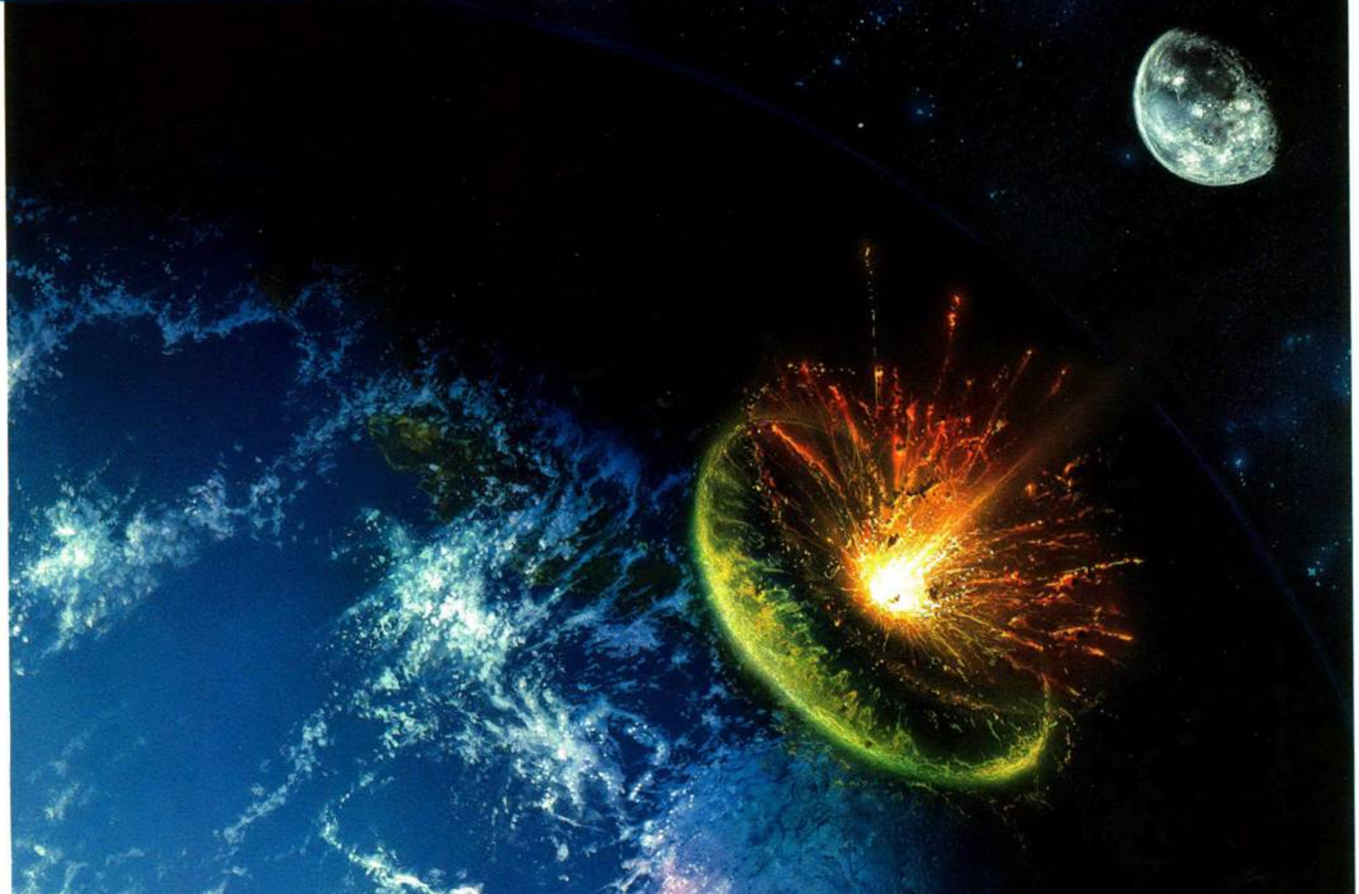

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Through June 30, 1991, Meade Instruments will give you Series 4000 Ultra Wide 8.8mm and 14mm eyepieces—the finest eyepieces obtainable—when you buy a Meade 8″ or 10″ Schmidt-Cassegrain with Smart Drive™!

in Meade® Ultra Wide Angle eyepieces, when you buy a Meade 8″ or 10″ SCT with Smart Drive.™

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1 Buy any of the following Meade Schmidt-Cassegrain telescope models with Smart Drive: 8″ 2080/Model 40, 46, 50, or 56; 10″ 2120/Model 40, 46, 50, or 56. Call or visit any authorized Meade dealer in the USA and Canada and make your best deal.

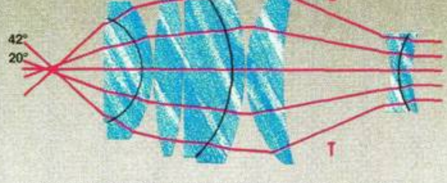
2 Mail to **Meade Instruments/Attn: Marketing Dept.** the completed Telescope Registration Card (included with each instrument), along with a copy of your invoice for the telescope you have purchased.

3 We will ship direct to your door and **free of charge** one each Meade Series 4000 Ultra Wide Angle 8.8mm and 14mm eyepieces.

This offer is valid only for telescopes purchased and delivered in the USA and Canada ***between May 1, 1991, and June 30, 1991.*** *Registration Cards and invoice copies sent to Meade Instruments must be postmarked not later than July 15, 1991.*

All eyepieces of this special offer are the exact same, brand-new, premium-grade Series 4000 Ultra Wide Angle eyepieces that we sell every day. **Regular retail value of the 2 Ultra Wide Angle eyepieces is $696.**

Meade 8-element Ultra Wide Angle eyepieces are the most sophisticated telescope ocular designs currently available. The ultimate in modern eyepieces, the UWA's permit extreme image fidelity and sharpness over an amazing 84° apparent field—wider than any other commercially available oculars.



Optical design of Meade Ultra Wide Angle eyepieces.

"Several hundred amateurs had the chance to test the performance of Meade Series 4000 eyepieces at the Astrofest Telescope Convention. Observing Jupiter with your Ultra Wide 8.8mm on a 7″ f/9 Starfire refractor, the huge 84° field encompassed the entire Jovian system. The four moons were resolved as discs, perfectly round even at the extreme edge of the field. Jupiter itself presented a magnificent show with a multitude of bands, small ovals, and festoons, etched in high contrast on the planet's surface. Meade Ultra Wide Angle eyepieces are a unique design that really brings out the best in a high performance telescope."

—**Roland Christen,** President, Astro-Physics Corp., Rockford, IL

Meade® SC Optic

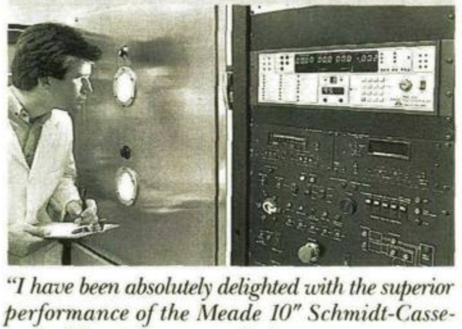
Keeping up with modern optical technology is an expensive process at Meade Instruments—but one which is absolutely vital to our continuing leadership in the production of Schmidt-Cassegrain optical systems. Long recognized as the finest commercially-produced Schmidt-Cassegrain optical systems available, Meade SC optics have recently been still further refined by the addition of important new equipment and processes—additions that assure the potential Meade SC purchaser that his or her telescope is, without qualification, state of the art.

New Super Multi-Coating (SMC): Now included as standard equipment on the correcting plates of most Meade 4″, 8″, and 10″ SCT models, the deep-purple Super Multi-Coating produces the highest light transmission of any antireflection coating in the industry.

Super Multi-Coating on the Meade 8″ 2080/Model 50.

At our Costa Mesa coating facility, Meade technicians use the latest electron beam vacuum coating systems to deposit, at 550°F, the hard, multi-layer chemistry of the SMC—a coating that perceptibly increases image brightness and contrast. Seven correcting plates can be coated on one plate side simultaneously; the plates are then automatically flipped internal to the vacuum system to permit coating of the opposite surfaces.

Electron beam vacuum coater.



"I have been absolutely delighted with the superior performance of the Meade 10″ Schmidt-Cassegrain. The optics are superb. At a recent star party Omega Centauri was resolved into thousands of tiny pinpoints into its core...Many said they were thrilled not only to see so much spiral structure in the Whirlpool Galaxy (M51) but also to see the faint bridge between the two components of M51."

—**L. J. Alfonso,** Boca Raton, FL

Primary Mirror Central Coring: Before Meade 4″, 8″ and 10″ SC primary mirrors can be polished and figured to within exacting optical tolerances, the central perforation, or

al Performance...“Superior...Superb...Breathtaking.”

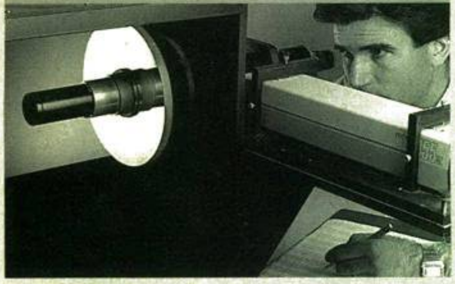
core, of each mirror blank must be precision diamond-ground into the blank. In the Meade optical shaping department this operation is performed on a 5-axis Computer Numerically Controlled (CNC) glass-machining center. The result is a mirror perforation (ready to accept the primary mirror baffle and focusing mechanism) that is within arc minutes of perfection—a precision that, with minor final adjustment by optical alignment technicians *(see below)*, virtually eliminates mechanically induced aberrations in the Schmidt optics.

CNC coring of SC primary mirrors.

“When unpacking my Meade 10″ SCT I realized that the amount of work which had gone into making this instrument was incredible...every detail was perfect down to the last nut and bolt. On the first clear night I took the scope out to check the optics. Quite simply the views were breathtaking! Star images matched textbook versions letter for letter, showing perfect symmetry in and out of focus.”
—**J. Spang,** Chorely, England.

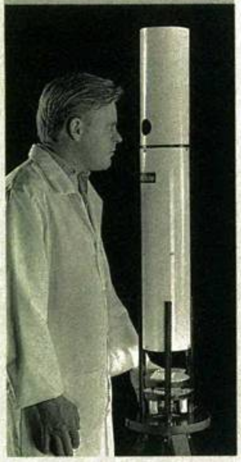
Optical Testing: As each Meade 3-element SC optical set (primary mirror, secondary mirror, and correcting plate) progresses through the grinding, polishing, and final hand-matching stages of development, it is continuously tested and re-tested for zonal irregularities, smoothness, and correction. Intermediate testing is performed using the Foucault and Ronchi methods; final diffraction image testing is done with a double-pass laser autocollimator that passes an intense pinhole of monochromatic light through the 3-element system *twice*, enabling the technician to detect errors (at an effective magnification of 1000X) beyond the observable limit of the field user. If we seem unusually confident in the capabilities of Meade Schmidt-Cassegrain optics, it is because we know that every optical set is put through this battery of over 30 separate optical tests and inspections before the optics are mounted in the optical tube and shipped to you.

Autocollimator testing of an 8″ SC system.



“Using my Meade 8″ SCT under just fair seeing the 1.0 arc sec double Zeta Boötes was beautifully separated, with plenty of dark space between the circular Airy discs. At lower power the four stars of Epsilon Lyrae were also cleanly separated and a beautiful sight, with all in the same field.”
—**R. Knight,** Stow, OH

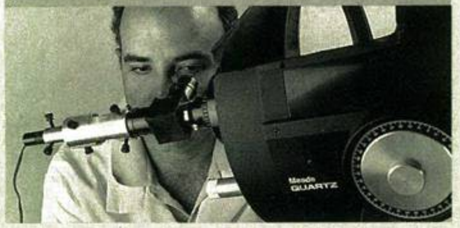
Interferometric testing of diagonal flats.



Diagonal Flat Testing: Integral to the functioning of any high-performance Cassegrain system is the optical smoothness and flatness of the diagonal surface. Every Meade diagonal mirror is tested for flatness on a Fizeau laser interferometer; mirrors which pass this test are coated with enhanced aluminum and mounted in their machined diagonal housings.

Optical Alignment: Finished, individually matched 4″, 8″ and 10″ SC optical sets are sent to the optical alignment department, where each set is placed into a special cut-out optical tube that permits rotation of the optical elements about the optical axis. (The relative rotational orientations of the Schmidt-Cassegrain primary mirror, secondary mirror, and correcting plate are *not* arbitrary.) Rotation of the optics, while the technician observes an artificial starpoint under controlled laboratory conditions at high power, yields the unique relative orientation that cancels out any residual aberrations of the system. With optimal orientation thus fixed, each optics set is placed into the machined housings of its optical tube. The optical system is once again tested for roundness, regularity, and consistency of the diffraction image inside and outside of focus. Only after passing this final test is an optical tube system ready to become part of a Meade Schmidt-Cassegrain telescope.

Rotational orienting of 10″ SC optics.



“As a former staff member at Mt. Wilson and Palomar Observatories, I have had access to some of the finest optics ever produced. The Meade 10″ f/6.3 2120 is the most impressive commercial instrument I have yet seen. Under critical examinations, stellar diffraction patterns are superb both inside and outside of focus. Focal images are sharp and crisp; in applications where high contrast characteristics are important (such as in observing the ‘eyes’ of the Owl Nebula, M97, or structural variations in the main spiral arm of the Whirlpool Galaxy, M51) the telescope performs impressively. The image of Saturn is beautifully defined, showing subtle belt detail and the crepe ring with surprising boldness for a 10″ telescope.”
—**Paul Roques,** Williams, AZ

Final quality control inspection.

Quality Control: As part of the final quality control inspection, an inspection which also includes detailed checkout of the telescope's mechanical and electronic functioning, each optical system is examined for any coating sleeks or scratches which may have occurred in the manufacturing process. Telescopes which pass this series of tests are then packed for shipment to authorized Meade dealers throughout the world.

Every Meade Schmidt-Cassegrain telescope must pass more than 135 optical, mechanical, and electronic tests, inspections, and quality control procedures before it is judged ready for shipment. If you're as committed to optical quality and performance as we are, then see what a Meade 4,″ 8,″ or 10″ Schmidt-Cassegrain can do for your observing program. See the telescopes that combine the finest, most integrated electromechanical systems, including the revolutionary Smart Drive,™ with the highest level of optical precision in the industry today.

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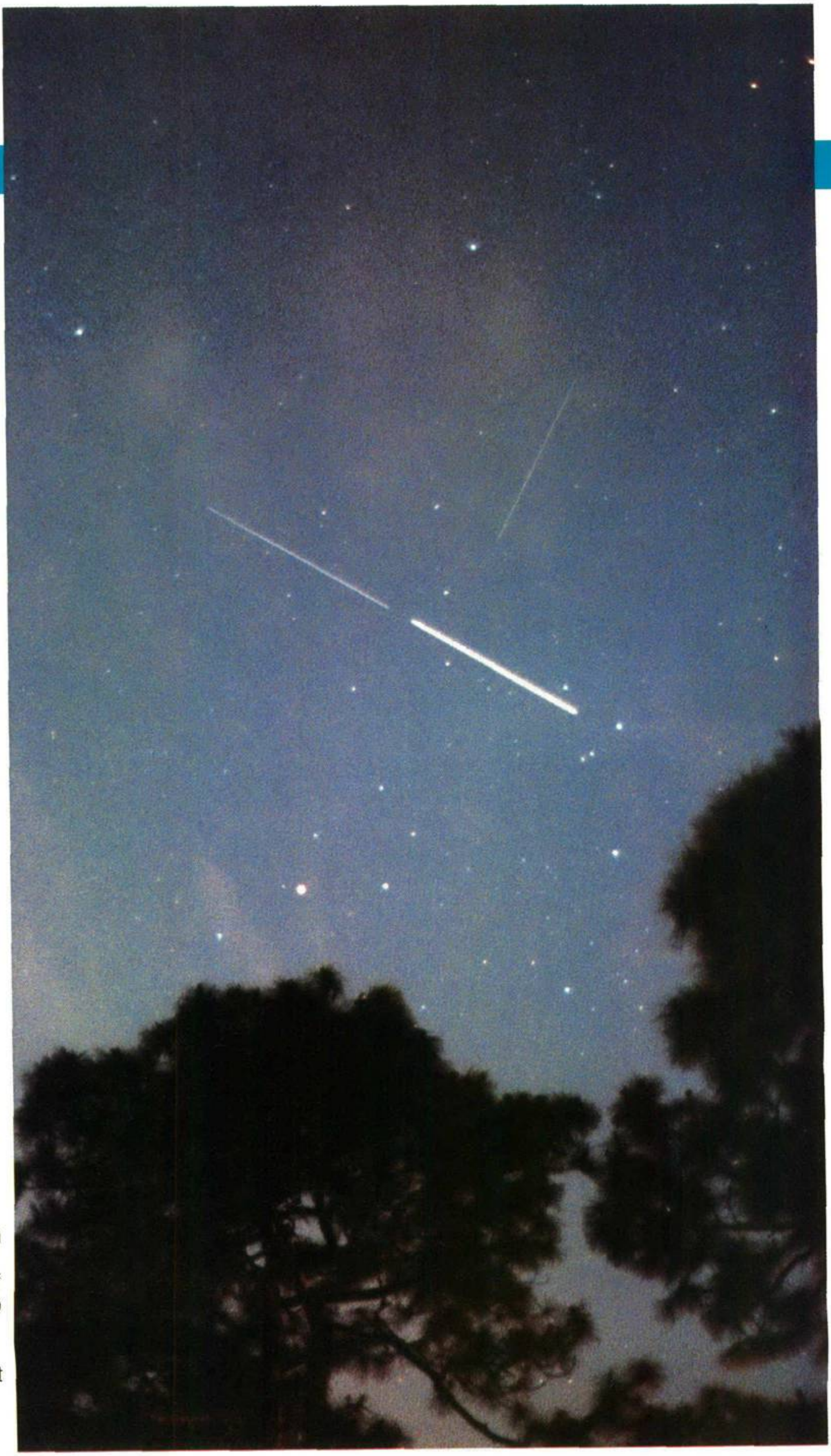
ON THE COVER: Sixty-five million years ago an asteroid smashing into what is now the Caribbean Sea near Mexico may have doomed the dinosaurs. For the complete story, see page 30. Art by Robert Eggleton.



IT WAS GO FOR GRO last April as the Gamma Ray Observatory was launched from the shuttle Atlantis. Sean Sullivan caught the two craft flying in formation through the stars of Scorpius on the morning of April 9. GRO is the streak to the left. The streak above the GRO/Atlantis pair is from a polar-orbiting Soviet satellite, Cosmos 206. See pages 26 and 44 for more about GRO.

ASTRONOMY®

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The Audit Bureau

Behind the Scenes

COVERING THE SUN

On July 11 the sky will darken and for a few brief minutes many ASTRONOMY readers will stand in the shadow of the Moon. We'll be there with you, sharing the excitement and the fun of the eclipse.

ASTRONOMY editors Alan Dyer, Dave Eicher, and Rich Talcott will watch the eclipse from the Baja Peninsula with a group from Twilight Tours. I'll be on the Adler Planetarium's *Viking Serenade* cruise ship. In addition to lecturing and running workshops, we plan to shoot lots of photos and videotape to document the eclipse and the scenes around us during totality, as will many of you.

To celebrate the occasion, we plan to run the finest portfolio of eclipse pictures ever assembled — and we'd like you to enter your pictures in ASTRONOMY's Eclipse 1991 Photo Contest.

Here are the categories you can win: Best Horizon Photo During Totality, Best Photo of Approaching Shadow, Best Wide-Angle View of the Sky, Best Closeup of Solar Prominences, Best Diamond Ring, Best Baily's Beads, Best Overall View of Corona, Best Coronal Streamers, Best Multiple-Exposure Photograph, Best Shadow Bands, Best Photo of Eclipse Preparations, Best Picture of Amateurs During Totality, and Best Eclipse Group Picture. We'll be looking for outstanding creativity, technical quality, and composition in each category.

If we discover more than one "winner" in a category, we'll award two prizes, or three, or as many winners as necessary. Top prize in each category will receive a check for $100 for each photo published; runners-up will receive $25 for each photo published.

Another category from which we'll select a winner is Best Videotape, but please realize that we can't put videos into the magazine! Don't send us your original videotape; send a VHS duplicate. The top videotape will receive a prize of $100.

All entries must be postmarked no later than August 5, 1991. The editors and the art department of ASTRONOMY magazine will evaluate all photos and tapes. Don't forget to include technical details.

We're looking forward to seeing your photographs and videotapes. As you shoot pictures of yourself and your friends preparing equipment for the eclipse, the approaching shadow of the Moon, and the corona blazing in the sky overhead — shoot a few extra frames. As soon as you get your pictures back from the photofinisher, place them securely between heavy cardboard, slip them into a sturdy envelope, and mail them to ASTRONOMY Solar Eclipse Contest, Box 1612, Waukesha, WI 52187.

Remember, there won't be another eclipse that lasts this long until 2132. Come join the editors of ASTRONOMY in celebrating and commemorating the Great Eclipse of 1991.

Sincerely,

Richard Berry

Richard Berry
Editor-in-Chief

ASTRONOMY

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Letters

Hope for Life at Alpha Centauri?

I thoroughly enjoyed Ken Croswell's article "Does Alpha Centauri Have Intelligent Life" (April issue). I did find one point in the article puzzling, however, and I hope you or Mr. Croswell can clear it up.

On at least three occasions, Croswell refers to red dwarfs (M-type stars) and cool K-type stars as having temperatures and luminosities insufficient to support life. Proxima is referred to as "hopeless," and its planets "must be lifeless." Yet I am still unclear as to why this is necessarily so. To my way of thinking, a cooler, dimmer star would simply have a narrower "life zone," as opposed to no life zone at all. And if so, a planet could exist in this life zone, leading to the possibility of life.

Is my thinking askew? Is there some characteristic of cool, dim stars that automatically precludes the possibility of life? — *Russell Wilson, Scottsdale, Arizona*

I enjoyed Ken Croswell's article immensely and agree with him on everything but one point. How can he claim an absolute time frame for the development of life on another planet? By definition his account of this is biased, being by necessity based on Earth's experience with developing life. I don't think it's fair to apply Earth-based Darwinism so concretely to other planets. — *Oswaldo J. Nunez, Caracas, Venezuela*

The excellent article by Ken Croswell inspired me to do some experimenting with my computer star cluster simulation program published in ASTRONOMY (September 1987 issue). It seemed unbelievable to me that any planet orbiting a star like Alpha Centauri A could remain stable if another star like Alpha Centauri B periodically passed within 11 astronomical units.

After a few educated guesses, I was able to simulate two stars that must be similar to the Alpha Centauri system. I placed two planets around the A star, much like Earth and Jupiter in terms of mass and distance. Croswell was right: the Earth-like planet remained in orbit about Alpha Centauri A. The Jupiter-like planet, however, was spectacularly ejected on the first pass of Alpha Centauri B.

One result of the simulation troubles

Ten out of ten software reviewers agree... There is now a new standard in astronomy software.

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The fascinating arena of the sky and solar system is now open to you in a new way. By combining realistic graphics with accurate orbital simulation, Dance of the Planets opens a cornucopia of possibilities for entertainment, education, and serious study. For just a taste: Go to Babylon to watch the solar eclipse of 136 bc. Witness Jupiter capturing comet Gehrels 3 in 1970. See where the satellites of Saturn are right now. Find the next good Mercury apparition. Watch Mars retrograde during opposition, then view it at up to 1000X. Watch the chaotic orbiting of Jupiter's outermost satellites, so perturbed by the Sun. Enjoy the lunar eclipses, occultations and conjunctions. Experiment with hypothetical asteroids to see how the Kirkwood gaps arise. See how the asteroid "belt" really looks, and locate or identify any known asteroid. Watch tails develop as comets near perihelion. Find a richly detailed, rotating Earth set among the stars. The possibilities with Dance are open ended–and mind opening.

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***Dance* has great potential in astronomy courses...An order of magnitude better than any other solar system simulator...**
John Mosley, **Sky & Telescope**, Dec. 1989

This reviewer has encountered no similarly rich entrant in the existing corpus of programs for the personal computer...
Phillip Morrison, **Scientific American**, Sep. 1990

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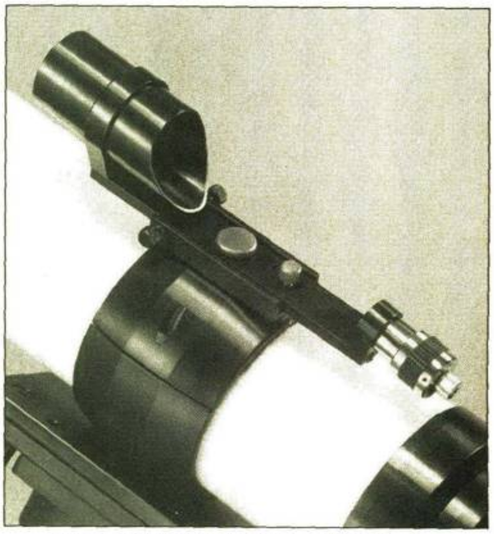

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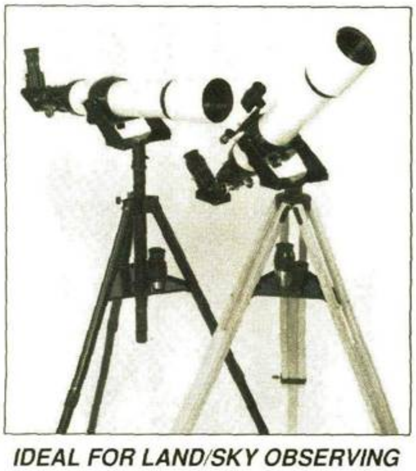
The Panoramic Mount is available with your choice of either an aluminum or wood tripod. The lightweight aluminum tripod has the same great features of the tripod used in the Tele-Pod. The wood tripod is beautifully crafted from American ash for added vibration damping. Both tripods include a convenient accessory tray.



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Anodized aluminum legs extend from 28" to 47" with an additional 18" of column extension. Rubber "foot-pads" contain retractable spikes for soft surfaces. Removable tray adds convenience and rigidity. The whole package weighs just 5 lbs.

Tele-Pod delivers a sturdy platform in a handy, lightweight package. Great for travelling quickly and easily with your telescope or camera.

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Systems Mount

Winning rave reviews for stability and versatility, the Tele Vue Systems Mount offers solid performance in a portable package. We start with a solid equatorial head featuring worm drive and slow motion controls. Choose our matching solid ash wood or sturdy aluminum tripod. This basic platform will easily support 25 lbs. of equipment.

Add optional accessories to build a system optimized for your needs. The battery operated motor drive makes dark-site astrophotography tracking convenient and accurate. The Polar Axis Telescope's unique reticle makes polar alignment easier than ever.

For astrophotography, the Systems Mount accepts optional guide scopes on the ±12° adjustable Fine Mount. All accessories, illuminators and adapters are described in our literature for the Systems Mount. When choosing a high quality equatorial mounting, "You can't beat the System!"

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Big Barlow™

NEW!

A Tele Vue 2x BIG Barlow will have a BIG impact on your observing. As with all Tele Vue Barlows, Al Nagler designed the BIG Barlow to improve eyepiece and telescope performance. Perfect for doubling the power while retaining the eye-relief of all Tele Vue eyepieces. Ideal for eyeglass wearers who love our 40mm and 32mm Wide Fields with their rubber eyeguards, but want more power.

The Big Barlow perfectly complements the stunning performance of Tele Vue's fast refractors. The multi-coated high index doublet and anti-reflection barrel threads maximize contrast. It even improves our competitor's eyepieces and telescopes!

The 2" BIG Barlow includes a parfocal 2" to 1-1/4" adapter, threads for 48mm filters and a captive lock-screw.

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AL IS INTO BARLOWS

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me. When the star pair (without planets) is allowed to orbit for several thousand years, the orbits slowly become more circular. Orbital periods become shorter and the distances between the two stars become more uniform. If the simulation is correct, it would imply that there might have been a time when the two stars were much closer together at perihelion than they are now. This may have caused the ejection of other planets that may have existed at Alpha Centauri even closer than Croswell's limit, thereby further reducing the chances for life around this star system. — *Thomas B. Woods, Jefferson, New Hampshire*

I found Croswell's article highly interesting but very speculative. I must object strongly to the assumption that "red dwarfs are too faint, too cool, to support life."

Croswell states that red dwarfs "do not give off enough energy to support life." The real question is how much energy reaches a prospective planet's surface. A planet orbiting sufficiently close to a red dwarf would receive just as much energy as a planet orbiting farther away from a hotter star.

I think it's a bit hasty to reject 70 percent of the stars in the Milky Way as candidates for life-supporting solar systems because they are cooler than our star. If there are civilizations advanced enough to have developed communication or transportation across interstellar distances — which there might be — they will have evolved in solar systems much older than our own. Red dwarfs would be the most likely candidates. — *Jeff Sterling, Rockledge, Florida*

— *Ken Croswell responds: The readers like red dwarfs as much as the Galaxy does! But few astronomers believe these stars support life. In order to receive enough energy, a planet orbiting a red dwarf would have to lie close to the star. The star would therefore exert huge tidal forces on the planet, causing one hemisphere to face the star and one hemisphere to face away from the star. The first hemisphere would become very hot, and the other hemisphere would get very cold. The atmosphere would boil away and freeze out from either side of the planet. This is not a good state of things for the survival of life.*

Of course this argument might be wrong, in which case the Galaxy may abound with red-dwarf-supported life forms who have probably convinced *themselves that life cannot exist around bright yellow stars like the Sun!*

Seeing the Difference

I was delighted to see the discussion of planetarium shows in your letters column (March issue). A reader asked whether planetaria have stopped demonstrating the effects of light pollution by showing city and country skies in succession. Thankfully the answer is no.

Today planetaria present programs ranging from the birth of the universe to the deaths of stars and everything in between. By far the most popular subject, however, is "the sky tonight."

I try to present the difference between city and country skies at every show, for children and adults. I want them to be aware of what they are missing if they don't see a dark sky. I also want them to go outside and find a constellation, a star, or a planet that may spark a lifelong interest in astronomy. — *Kris McCall, director, Sudekum Planetarium, Nashville, Tennessee*

As a planetarium director in a northwestern New Jersey high school, I'm acutely aware of the problems posed by unshielded lighting. I include in each planetarium program a presentation that illustrates the sky locally, the sky closer to New York City (which is 50 miles away), and a dark country sky. The message is overwhelming to the students who see it for themselves. I urge my fellow planetarians to incorporate this demonstration into their shows if they aren't already doing so. — *John C. Scala, Director, Lenape Valley Regional High School Planetarium, Stanhope, New Jersey*

Where's the Reef?

In the otherwise excellent article "Galileo's Flyby of Earth and the Moon" (March issue), the caption for the infrared spectrometer image on page 32 contains an error. The caption says that the Great Barrier Reef is visible in the upper left part of the photo. When I lived in Australia years ago the Great Barrier Reef was along the Queensland coast, in the upper right section of the image. Has there been a recent tectonic plate shift that has changed this? — *Anthony Russell, Beresford, New Brunswick, Canada*

— Yikes! We'll have to avoid misplacing parts of Australia in our next issue.

A Spot Discovery

Alan Dyer's article "Tracking the Great White" (March issue) contains a misperception concerning Stuart Wilbur's discovery of the Saturnian spot.

Wilbur did not "quickly report his observation" to the International Astronomical Union without confirmation. Instead, he reported it to Clyde Tombaugh, discoverer of Pluto, who recommended Wilbur contact Reta Beebe at New Mexico State University. At this time Clyde mentioned the spot to me, and I sent an electronic mail message to Dan Green at the IAU.

Not only did Stu Wilbur confirm his observation before his report went to the IAU, but the spot was also confirmed by two experienced planetary observers. — *Alan Hale, Las Cruces, New Mexico*

— We reported that Wilbur "quickly reported his observation to the Smithsonian Astrophysical Observatory in Cambridge, Massachusetts." We did not report one way or the other about the observation's confirmation.

The Accessibility Factor

Being a disabled amateur astronomer myself, I enjoyed reading "Making the Sky Accessible" (April issue). I recently turned down an invitation to join a night viewing group offered to astronomy students at Idaho State University in Pocatello. Although I find my schoolmates willing to help me, I still feel overwhelmed. We can all help the interested but disabled to have a great time in amateur astronomy. — *William E. Barton, Pocatello, Idaho*

Corrections

The dates for the Alberta Star Party at Waterton Lakes National Park should be August 16 to 18, not August 10 to 11 as listed in the May issue Astronomy Activity Guide.

In the June issue, "ROSAT's Penetrating X-ray Visions" lists the Uhuru satellite as British-built. It was in fact a NASA satellite built by American Science and Engineering and launched in 1970 from the San Marco launch facility off the coast of Kenya. ☐

ASTRONOMY welcomes comments, suggestions, and additional information on articles and astronomy in general. Send your letters to: ASTRONOMY Letters, P.O. Box 1612, Waukesha, WI 53187. Letters may be edited for length or clarity.

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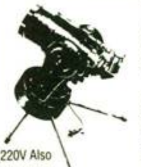

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ASTRONOMY IN THE AGE OF MTV

by Michael Porcellino

Part of the fun of being an amateur astronomer is sharing the beauty and wonder of the night sky with others. Developing an interest in astronomy can be difficult, however, when science is viewed as drudgery by students and the public. The astronomy hobby does take a certain amount of work and personal involvement. It is much easier to kick back in front of the electric fireplace and tune in MTV than it is to take out the scope and tune in the universe. The only way for astronomy clubs to overcome the lure of MTV is through public education.

The local astronomy club is often the only outlet many communities have for information on the cosmos. This is especially true of small communities. But even in large cities, astronomy clubs can play a vital role in increasing public awareness of what is happening in the universe. The launches of the Hubble Space Telescope and the Gamma Ray Observatory have already whetted the public's appetite for more information on "what's out there." Making the local astronomy club a source for that information is the role of an effective and active education program.

Astronomy clubs approach public education in a number of ways. Probably the most common form of public education is the public observing session. To give you an example of how this works, let's look at the efforts of several clubs. Working with the Metropark District of Cleveland, for example, the Cuyahoga Astronomical Association (CAA) sponsors a program of 10 public observing sessions per year at nature centers throughout the area. At some of these sessions, attended by between 40 and 50 people, a lecture on observing techniques and what the people will be seeing precedes telescopic observing. This schedule of lectures and public observing has served to heighten public interest in both the CAA and astronomy. In addition to their regular public observing sessions, the CAA offers special programs. Their recent "Telescopes at the Zoo," held in conjunction with a local zoo, saw 2,000 people turn out to peek through telescopes. "These sessions have done a lot to let the public know we are here," says Al Jenkins of the CAA.

Even light pollution cannot curtail public observing programs. Members of the Amateur Astronomers Association (AAA) of New York set up telescopes at a variety of locations throughout the city. City parks, Floyd Bennet Field in

Brooklyn, and Great Kills Park on Staten Island are all locations for AAA public observing. According to John Pazmino, AAA President, attendance runs between 30 and 50 at these sessions.

In New Mexico, the Albuquerque Astronomical Society (AAS) takes a vigorous approach to public education. The Society works with the University of New Mexico Observatory by providing volunteer operators for the observatory's public nights. In addition to the University's telescope, members set up their own scopes to give the public a chance to see a variety of objects in a number of different telescopes. "While the outside viewing is going on we run a continuous slide show inside so folks can come anytime and not miss anything," says AAS President David Finley. This is the third year of the AAS/UNM program and both are happy with its results.

Public observing is only one way for clubs to reach the public. Many clubs offer programs separate from public observing. "We regard astronomy as cultural enlightenment and believe we have a public mission," says John Pazmino, "and observing is but one facet of our astronomy experience. We offer classes on astronomy at a number of city locations, including our headquarters." These run the gamut from informal stargazing to instruction on how to use a telescope to formal lectures on the science for the public. "Many of our members use these functions to enhance and advance their own astronomy."

Amateur Astronomers Inc. (AAI) of New Jersey has carried this aspect of public education one step further. In 1968 they established a program with the Union County College to offer a course on astronomy. AAI members developed and teach this non-credit course while the college promotes the course. "It has been a very good relationship," says George Chaplenko, AAI corresponding secretary. "The average enrollment for the course is about 20 to 25 people and 30 percent eventually join our group." In addition to the course the AAI helps out by providing operators for weekly open houses at the college's Sperry Observatory. These public sessions draw anywhere from 30 to 300 people. The group also provides the college with a list of topics that members can speak about when the college forwards requests for speakers to the club.

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ASTROPHOTO OF THE MONTH

Galaxies NGC 4631 (left) **and NGC 4656/7** (right) **in Canes Venatici.** 50 minute exposure by Martin Germano *using 2415 hypered in a* LUMICON *Hyper-Kit and an 8"* f/5 telescope with a LUMICON 2" Newtonian Easy-Guider. Much detail can be seen *in 9th magnitude* NGC 4631. Look for nearby 12th magnitude NGC 4627. NGC 4656/7 has an interesting hook; look for the hard-to-see faint extension doubling its length.

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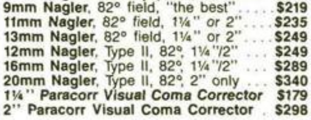

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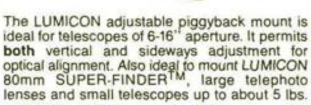

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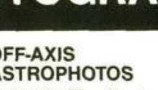

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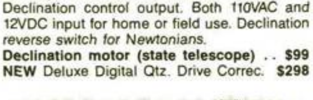

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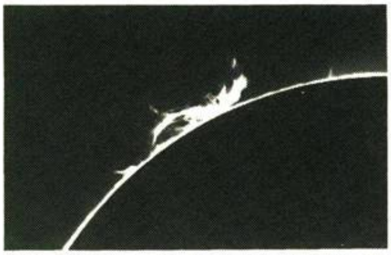
LUMICON® H-ALPHA SOLAR PROMINENCE FILTER

ECLIPSE SPECIAL: $495 if ordered before July 15, 1991. Regularly $595

Solar Surface detail, showing sunspots and flares, through a LUMICON 1.4 Å Solar Prominence Filter. Photo by Maxime Muller, 90mm f/30 refractor on Feb. 2, 1991, 2415 film.



Solar Prominence detail photographed by Jim Baumgardt through a 1½ Angstrom LUMICON Solar Prominence Filter. 12½" Newtonian telescope at f/70 using eyepiece projection, 1/125 second exposure using 2415 film on 6-25-83. Solar surface masked during printing to give an eclipse-like effect.

LUMICON Solar Prominence Filter for viewing and with camera adapter attached. The thumb-screw allows filter tuning.

This high performance LUMICON Filter has a very narrow 1.2 Angstrom (1.0-1.4 Å) bandpass, which transmits only the red H-Alpha Line at 6563 Angstroms. It includes an adapter for viewing with 1¼" eyepieces and includes a tuning mechanism by tilting, which allows you to optimize transmission and contrast for the particular features you are examining. No heater is required.

This filter has a 22mm clear aperture and has built-in camera T-threads for easy use in photography (see photo above). For photography the 1¼" eyepiece viewing adapter is removed and a standard camera T-ring threaded on, as shown in the photo above.

LUMICON H-Alpha Solar Prominence Filter, 1.2 Angstrom, fits 2" focusing mounts	**$595**
SPECIAL PRICE — $495 if ordered before July 15, 1991	
2" Accessory adapter for C-5, C-8, C-11, C-14, Meade 2045, 2080, 2120	**$26**
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All LUMICON Solar Prominence Filters are designed to insert into 2" i.d. focusing mounts or 2" eyepiece holders. Adapters allow use with 1¼" optical systems. Schmidt-Cassegrain telescopes like Meade 2080, 2120, Celestron C-5, C-8, C-11, C-14 require a 2" accessory adapter.

The energy rejection pre-filter is included with the LUMICON Solar Prominence Filter and **must** be used with it. The pre-filter mounts in an off-axis mask with 77mm (3.03") hole on the front of the telescope. 3" metal off-axis masks are available for C-8, Meade 2080, Meade 2120, C-11 and C-14. The pre-filter is installed at no charge if the off-axis mask is ordered with the prominence filter.

Adapter to mount Solar Prominence Filter in 1¼" focusing mounts	**$22**
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2080 Model 46SD, 8" f/6	**$1799**
2120 Model 40SD, 10" f/10	**$2099**
2120 Model 46SD, 10" f/6	**$2298**
Model 2600 16" f/10	**$9950**

Options Enhance Performance

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#39 Declination motor	**Add $109**
Digital setting circle	**Add $399**
2" Star diagonal	**Add $179**
LUMICON Cassegrain Easy-Guider *(Please specify camera)*	**Add $225**
LUMICON Giant Easy-Guider (for #40) *(Specify camera)*	**Add $395**
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PREMIER 2080
Model 50SD
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Meade Premier 2080 Model 50SD

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Coma 1 inch off-axis 17½" f/4.5

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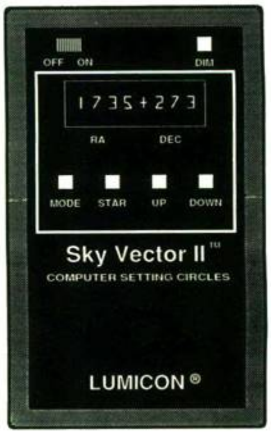

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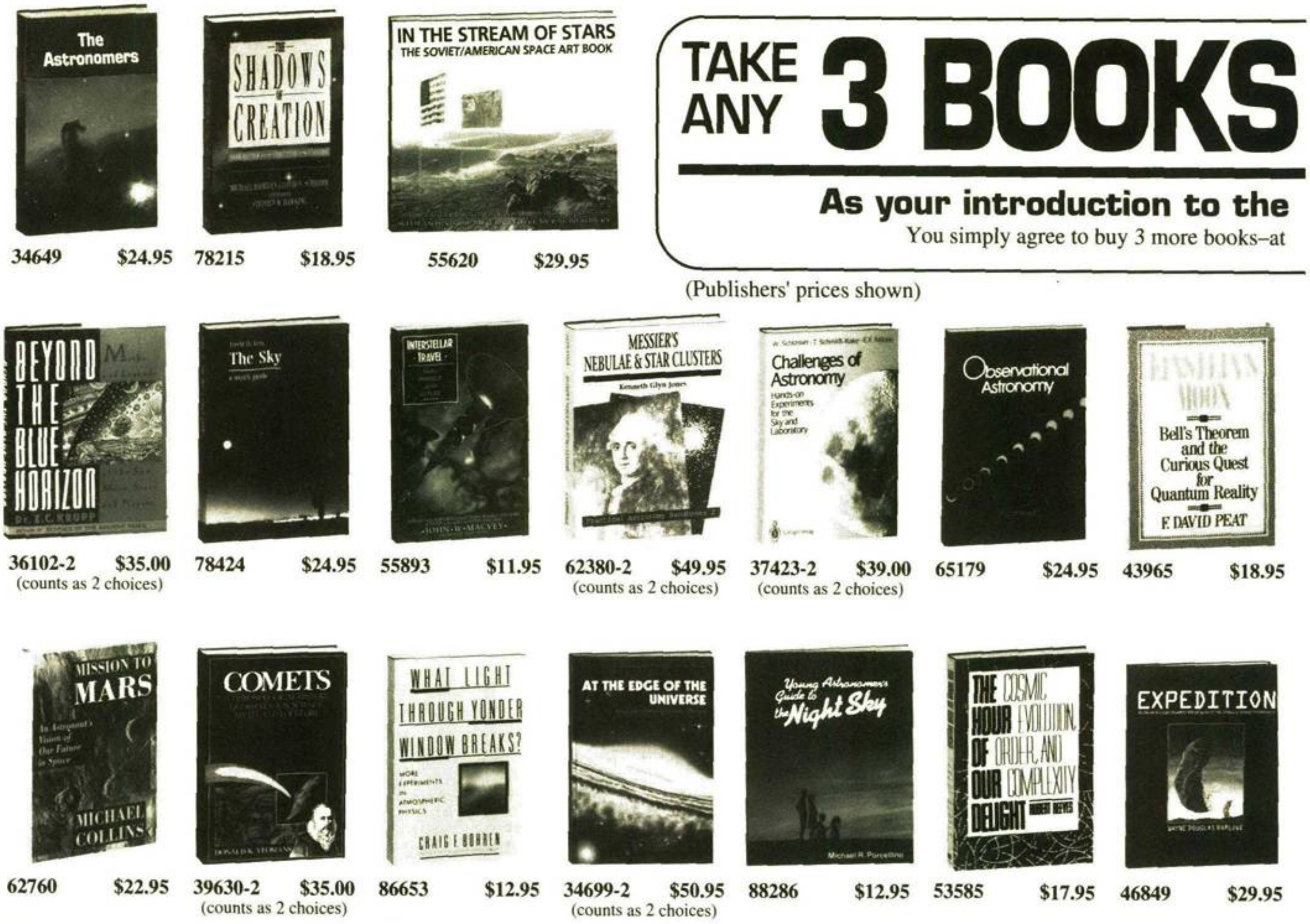

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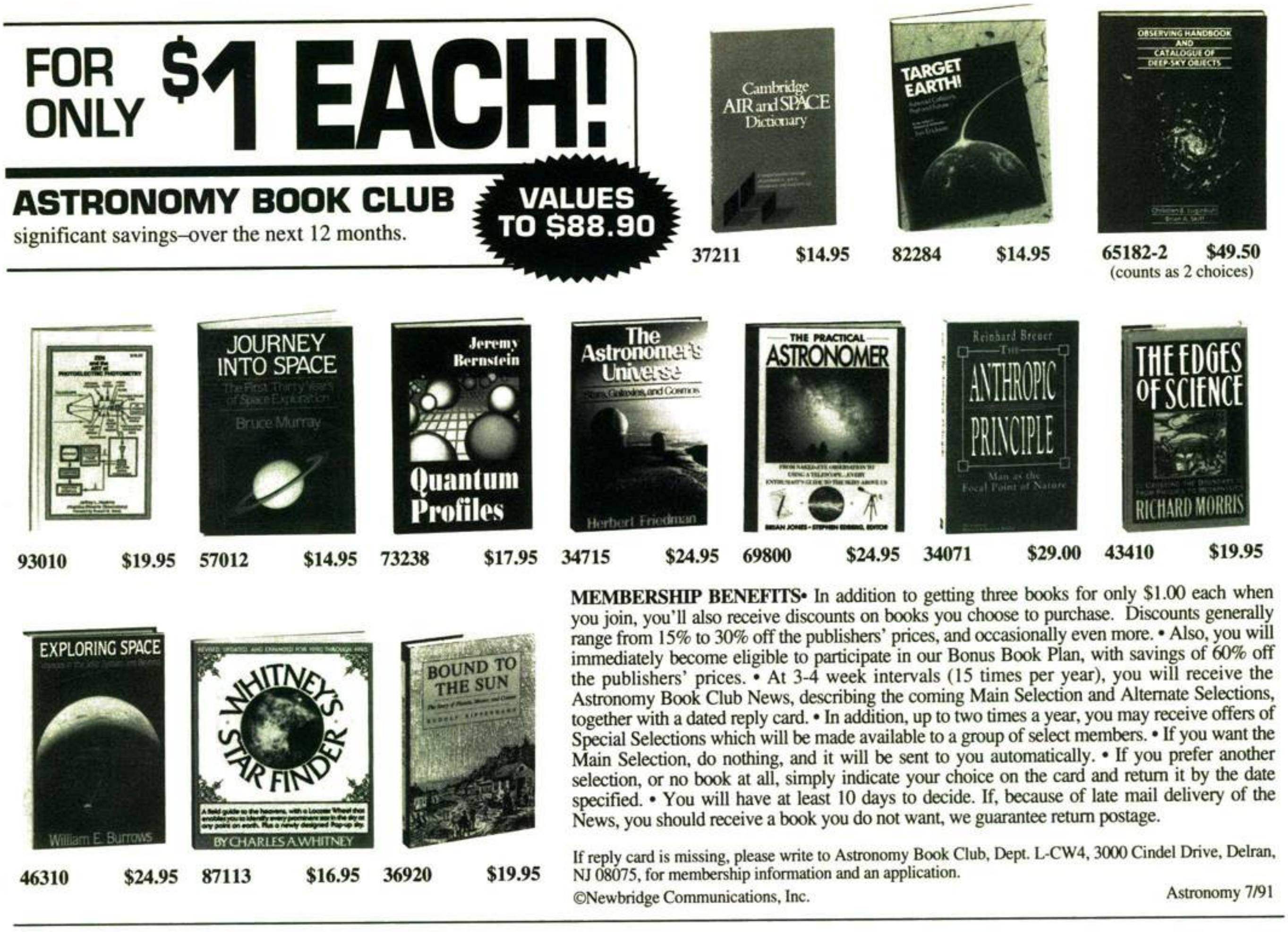
To help astronomy grow, we need to reach our youth. "Astronomy clubs can do a lot to generate interest in the science on the school level," says Al Jenkins. While the CAA does not have a formal school program, members do visit and talk to schools on a regular basis.

Other groups have more active school programs. The Albuquerque Astronomical Society has 20 to 30 members active in their program. "We've been working with the school system here for 10 years or so," says David Finley. "Our members work with parent-teacher associations and the school system science coordinator. The schools know what we can do and don't hesitate to ask for our assistance." In addition, the local planetarium director will funnel speaker requests to the club. Does a school program have an impact on the club and the public perception of amateur astronomy? Potentially. "Last year we reached over 7,300 people with our education program," replied Finley.

Just as important as reaching the school children is reaching their teachers. Many teachers are intimidated by having to teach a section on astronomy. Although many teachers have taken some science courses in college, astronomy is often overlooked, appearing as a subsection in a general science or physics course. Astronomy clubs can do something to help in this area. In 1989, the Baton Rouge Astronomical Society (BRAS) offered to set up telescopes for viewing by teachers attending the Louisiana Science Teachers' Convention being held in that city. "The response was overwhelming," according to Mark Stauffer, BRAS president. "Many of the teachers had never seen what they were talking to their students about! It made astronomy real for them." The session was so well received that there are plans for the BRAS to conduct a seminar on teaching astronomy at this year's convention.

Is this approach of "taking astronomy to the people" worthwhile for a club? "You bet," says David Finley. "A good public education program gives you credibility and generates good-will." The media tend to pay no attention to amateur astronomers. "They seem to ignore what many of us do simply because we bear the label of amateur astronomer," says Bill Becker of the Chicago Astronomical Society. An effective education program shows the people that your club is a legitimate community resource. "We're generating support for our big project, the construction of the General Nathan Twining Observatory, because we have a public education program. Individuals and corporations are more likely to support us because of the public aspect of our program."

Developing support for a project like a society observatory is only one of the byproducts of an effective public education program. One of the most obvious, and often overlooked, benefits is attracting new members. There has been rather heated debate in some circles as to the future of amateur astronomy in this country. One side says amateur astronomy is doomed while the other claims our hobby is strong and growing. The entire issue comes down to generating interest in astronomy as both a science and a hobby. This, in turn, will attract new members. It stands to reason that a club that can



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Astronomy 7/91

sign up new blood will grow and continue to be strong. But if a club sits on the sidelines and allows the science-as-drudgery image to flourish it will find itself in trouble. The only way to avoid this is to have an effective and active education program.

There are a number of ways your society can establish or expand its astronomy education program. Here are some suggestions that even the smallest club can put to good use:

•**Contact local colleges**. Let the people who teach astronomy know that you and your group are out there. Invite them to meetings and star parties, or even to address your group. If members of your group agree, volunteer to conduct observing sessions for their classes. Let the college know that you can handle requests for speakers on a variety of astronomy and space-related topics and have the college forward such requests to your group.

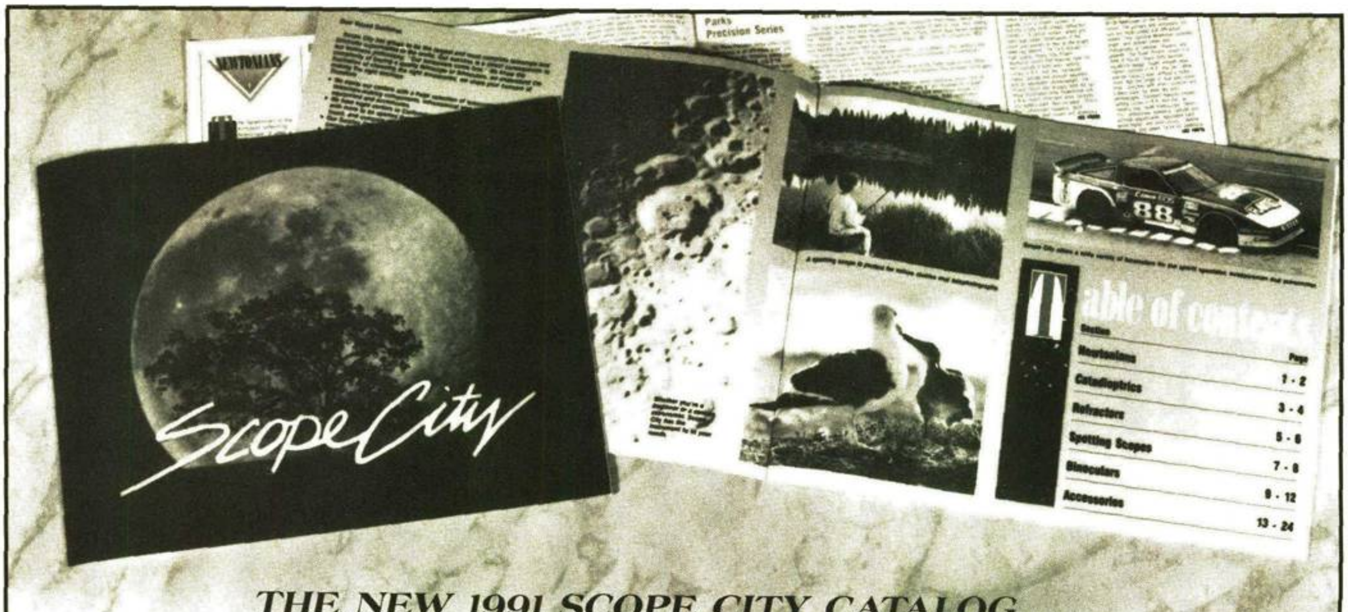
•**Contact local schools**. Get in touch with teachers in your schools at all levels, all the way up to your school board. Let them know you are there and willing to help make science and astronomy a real experience for their students. Send copies of your newsletter to the local schools and invite teachers to your meetings and public events. Get them interested and they will open more and more doors for you.

•**Contact local media**. The public can't become involved in your program if they don't know you are there. Work with the local media — print, radio, and TV — to let them know about public observing sessions and special events. Media relations in each city presents its own special problems. It is easier to generate media interest in club activities in a small market because the media are often hungry for features to tantalize the public. In a large market the media are often overwhelmed by such local events as the latest gang violence or juicy murder. But even in these large markets, a place for your public education program exists. Offer to make your group's telescopes available to local TV for live feeds of a bright planet, the Moon, or a large sunspot group. Offer local radio stations your group's expertise in explaining "strange" celestial events. Send copies of your club newsletter to the print media and tell them it's okay to use articles from it as long as they credit the author and your club. Remember you have commodities that are absolutely vital to any local media operation — information and expertise.

•**Work with local organizations, groups, and corporations**. If you have a couple of good public speakers in your group, develop a list of topics about astronomy and space science. Try to key some of the topics to local interests if at all possible.

•**Couple public observing with specific celestial events**. While a lunar or solar eclipse doesn't come along every day, begin your planning for the next one well ahead of time. Press releases on the event should be sent out with enough time to build public interest in the event. If there is nothing on the "event horizon" for a couple of years, take advantage of what is going to happen in the near future. A close appulse of two planets or the moon and a planet can develop into a media event — if it is handled correctly. The Mars opposition for 1990 may not have been as good as the previous one in 1988, but Mars is a planet that everybody seems to love.

The role of the local astronomy club can run across a broad spectrum of approaches to educating the public about astronomy. Despite the variety of approaches to public education, some clubs look at education almost as an afterthought to their other activities. Others devote much effort to gaining exposure and acceptance in educating the public. Which road your club takes is, of course, up to you and your fellow members. But astronomy is exciting enough so that any club can challenge MTV for the hearts and minds of the public. ☐



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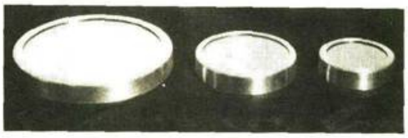

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TYPE 2 - Same as type 1, except stainless steel is combined in the coating to provide an even more durable surface that highly resists wear due to excessive handling and ultraviolet radiation. Solar image is also yellow-orange.

TYPE 3 - Coated to a neutral density of 4 for serious astrophotographers who desire the shortest possible shutter speeds with slow films. Solar image and optical quality same as type 1 and 2. Type 3 filters are for photographic use only.

Type 1 & 2 are for unlimited visual use and general photographic use. Instructions included with all filters, including tips on solar photography.

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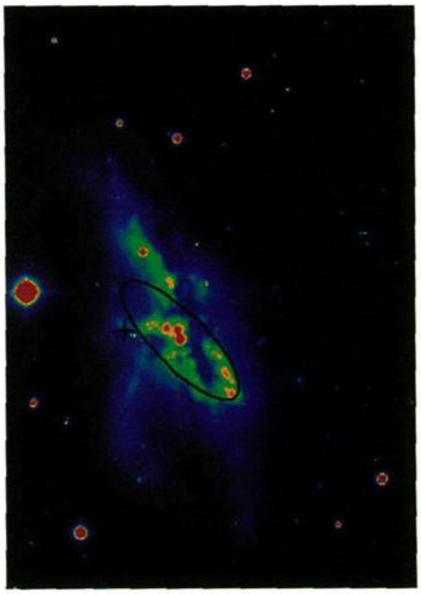
AN ULTRAMASSIVE BLACK HOLE?

Astronomers have discovered a massive, dark, and compact object that dwarfs the most massive black hole previously suspected. Weighing in at 100 billion solar masses — ten to one hundred times larger than any prior black hole candidates — the enormous object may be the first example of a new class of ultramassive black holes.

Joss Bland-Hawthorn of Rice University, Andrew Wilson of the University of Maryland, and Brent Tully of the University of Hawaii discovered this intriguing object in the distant galaxy NGC 6240, located some 300 million light-years away in the constellation Ophiuchus. Their interest in NGC 6240 began with a 1983 survey by the Infrared Astronomical Satellite that showed the galaxy to be an extremely bright infrared source, radiating some one trillion times the Sun's luminosity in just the infrared. Like all highly luminous infrared galaxies, NGC 6240 is a system of two colliding galaxies, and at least some of its unusual properties stem from this.

In a study published in the April 10 issue of *Astrophysical Journal Letters*, Bland-Hawthorn, Wilson, and Tully explained how they mapped NGC 6240 with a new interferometer attached to the University of Hawaii's 88-inch telescope on Mauna Kea. By measuring the Doppler shift in the H-alpha spectral line of hydrogen, they found that NGC 6240 contains not just one spinning disk of gas, but two. The first disk, which is centered on the light emitted at visible wavelengths, rotates much like an ordinary galaxy, with the gases swirling around the center at speeds governed by the mass of the galaxy's stars and other material.



MASSIVE, DARK, AND COMPACT, a mysterious object in the galaxy NGC 6240 may be the most massive black hole yet discovered. The cross marks the position of the suspected black hole, which is embedded in a disk of gas that does not show up on this photo. The ellipse delineates the extent of a second gaseous disk that rotates like a normal galaxy. Photo courtesy Rice University.

The structure of the second disk, however, is quite remarkable. At a distance of about 4,000 light-years from the disk's center, the rotational velocity of the gas is a whopping 400 kilometers per second. Outside this region, the rotational velocity drops rapidly, in a manner similar to but more pronounced than the way the planets' orbital velocities decrease the farther away they are from the Sun.

The high rotation velocity of the inner disk implies that the mass within a 4,000-light-year radius of the disk's center is at least 40 billion solar masses and may be as high as 200 billion solar masses. That's about the mass of the entire Milky Way Galaxy, but it's concentrated in a volume only 0.01 percent as big as the Milky Way. Despite the huge mass, the central region of the disk is quite dark — at least 60 times darker for its mass as the Sun is.

What is this object? The most plausible explanation is that it is a supermassive black hole. In principle, the massive dark object could result from a trillion brown dwarfs (objects larger than planets but smaller than stars) or 100 billion neutron stars crammed into the disk's nucleus, but the problem lies in explaining why such a huge number of stars would be concentrated there. And even if such a situation developed, it's likely the objects would ultimately collapse into a black hole anyway.

But the size of this possible black hole is unique. Up to now, the largest suspected black hole was in the giant elliptical galaxy M87, and that one contains "only" a few billion solar masses of material. Most astronomers suspect that quasars also harbor supermassive black holes, with the quasars' prodigious energy outputs coming from matter being swallowed by the black holes.

In fact, the object in NGC 6240 could well be related to the quasars. These superluminous objects were common in the early universe, but are very rare today. Yet if they were once powered by supermassive black holes, those black holes must still exist. Starved of fresh material, however, they would show up as dark objects with masses of billions of Suns — just like the object in NGC 6240.

Bland-Hawthorn, Wilson, and Tully plan to follow up their discovery by observing NGC 6240 with the ROSAT x-ray satellite and, they hope, with the newly launched Gamma Ray Observatory (see story beginning on page 44). Detecting x rays or gamma rays from the object would bolster the case that the object is a black hole. In the meantime, the researchers are planning to continue their search of infrared galaxies, hoping to find more examples of these ultramassive objects.

MOST DISTANT "ASTEROID" DISCOVERED

A new asteroid-like body with unique orbital properties was discovered by astronomers in Australia using the U. K. Schmidt Telescope on February 18, 1991. Perhaps an asteroid with a highly distorted orbit, perhaps the burnt-out nucleus of a defunct comet, the object has planetary astronomers scrambling for explanations. Whatever its past history, the object now has a highly inclined, eccentric orbit that carries it as close to the Sun as 1.6 astronomical units and as distant as 22.0 astronomical units — beyond the orbit of Uranus. Provisionally designated 1991 DA, the object was at first thought to be nothing more than a fast-moving, near-Earth asteroid. Subsequent analysis by Robert McNaught of the University of Adelaide resulted in a much different outcome, however.

McNaught used the Uppsala Southern Schmidt Telescope to make enough observations of the object to derive an orbit. The observations were rather difficult to make and analyze because last spring 1991 DA glowed feebly at 17th magnitude. (At that time the object was 200 million miles from Earth and moving away at 40,000 miles per hour.)

Once he had gathered enough data

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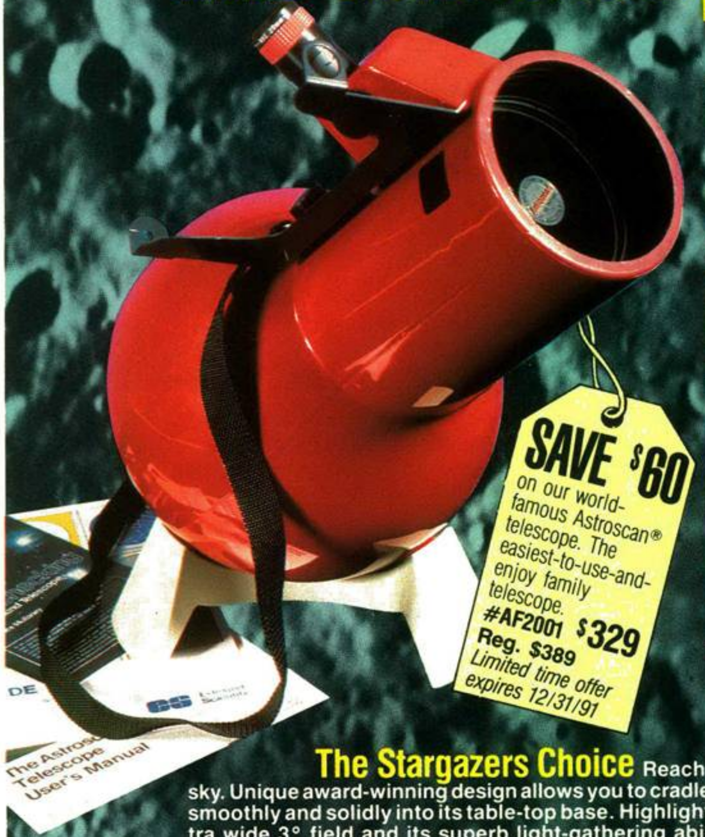

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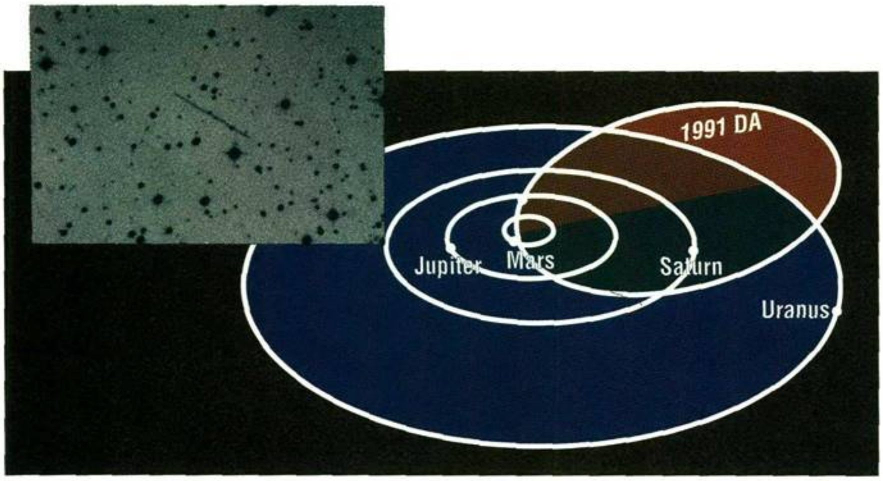

A TINY STREAK marks the track of the unusual object 1991 DA, a 5-kilometer chunk of material that could be a defunct comet. This section of the discovery plate, made with the U. K. Schmidt Telescope, was supplied by Rob McNaught. The diagram shows the unusually large, elongated path of 1991 DA through the solar system. Positions shown are for July 15, 1991.

to determine an orbit, McNaught was surprised. The object's orbit is so elongated that it is carried out much farther than any known asteroid and much closer toward the Sun than most asteroids — at perihelion, 1991 DA lies within the Martian orbit. The orbit more closely resembles that of a comet than an asteroid, yet there is no cloud of material surrounding this object — if it was once a comet, it is now "dead."

That 1991 DA is not a currently active comet was confirmed by McNaught and Duncan Steel on March 18. They used the 4-meter Anglo-Australian Telescope at Siding Spring and found a complete lack of any comet-like activity. The only similar objects are an asteroid discovered in 1920 and the mysterious object Chiron (found in 1977), although Chiron has recently been shown to be a comet. The orbital period of 1991 DA is about 41 years, which will give astronomers sufficient time to place the new object in some class of solar system body — asteroid, comet, or something new, odd, and unique.

DISK GALAXY PLAYS HOST TO BL LAC OBJECT

For the first time, astronomers have found a BL Lac object in a galaxy dominated by a large flattened disk. This is an unprecendented discovery because the BL Lac objects known to date have been found only in elliptical galaxies, which do not have disks. The new finding casts doubt on current theories that explain these mysterious objects. The discovery was made by an international team of astronomers headed by Ian McHardy of Southampton University in England.

The prototype object, BL Lacertae, was discovered in 1929 and was at first mistaken for a variable star. In the 1960s, however, BL Lac was found to emit radio noise and to be surrounded

Amateur News

TELESCOPES FOR PLANETARY OBSERVERS

The Association of Lunar and Planetary Observers (ALPO) has established a program to assist amateur planetary observers around the world. The fund, called the International Solar System Observers' Fund (ISSOF), will serve as a focal point for distributing equipment and observing aids worldwide to amateur astronomers. Recipients of the equipment are expected to contribute observations to ALPO solar system programs. The new fund has been organized by ALPO member Paul H. Bock, Jr. Bock now serves as coordinator of the ISSOF.

Because the ISSOF is a voluntary effort, it must be supported by contributions. All contributions to the fund are tax deductible. In addition, ALPO intends to provide free publicity to commercial contributors through regular reports of ISSOF status in *The Strolling Astronomer*, the journal of the ALPO, as well as in ASTRONOMY.

Currently, ISSOF is collecting funds and material to support observers in Romania, Tanzania, Algeria, and Poland. The most unusual request for equipment so far has come from Dr. Matei Alexescu of Bacau, Romania. Dr. Alexescu's 8-inch Cassegrain telescope was rendered unusable late in 1989 when the primary mirror was destroyed by gunfire during the political upheaval in his country. A new mirror set is being manufactured free of charge by master optician Bob Goff of Tucson, Arizona.

To assist a group of amateur astronomers in Tanzania who have no equipment at all (not even binoculars), Bock is constructing a 60mm refractor and mount. A commercial optical firm, D&G Optical of East Petersburg, Pennsylvania, has volunteered free optical testing and lens alignment services to ISSOF in support of this and similar projects. D&G Optical makes medium-aperture achromatic refractors.

The observers who ISSOF can help need eyepieces, mirror blanks, color filters, star charts, sky atlases, as well as color slides and posters for popularizing astronomy in their native countries. Anyone wishing to contribute equipment or supplies to the ISSOF should write to Bock at the address below. He will forward a list of current requirements, along with the necessary forms to ensure that contributors receive proper tax credit for their donation. Amateur astronomers who can contribute telescopes and observing equipment should contact him at this address: Paul H. Bock, Jr., RR1, Box 347 Hamilton, VA 22068.

Amateur astronomers who wish to make a financial contribution to the ISSOF fund rather than a donation of equipment should write to Dr. John E. Westfall, Executive Director, ALPO, P.O. Box 16131, San Francisco, CA 94116.

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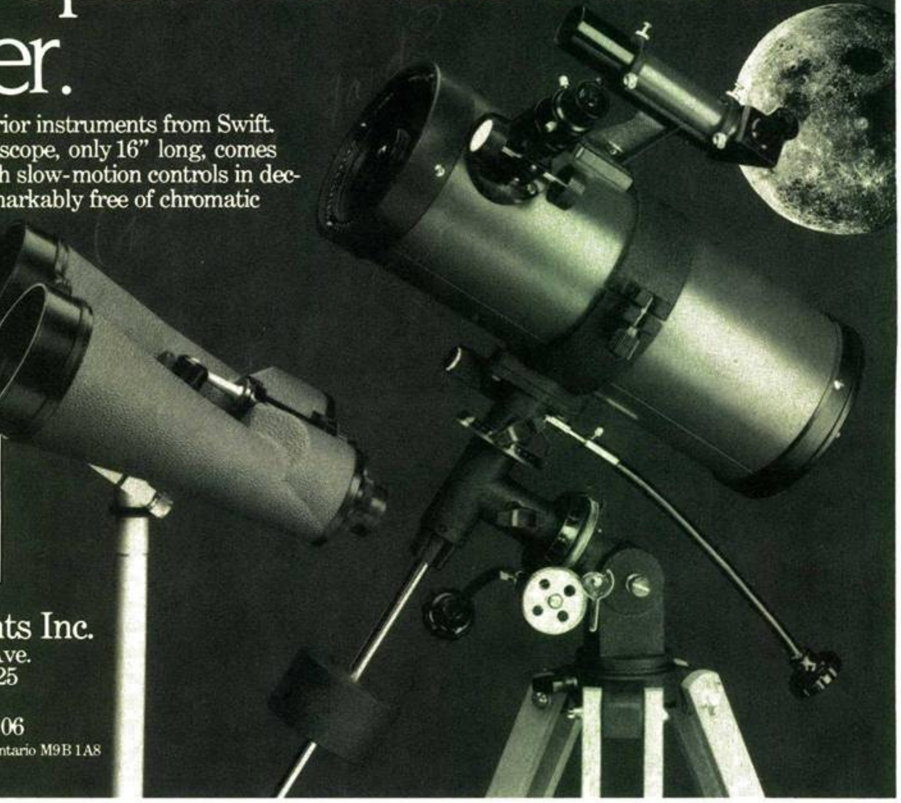

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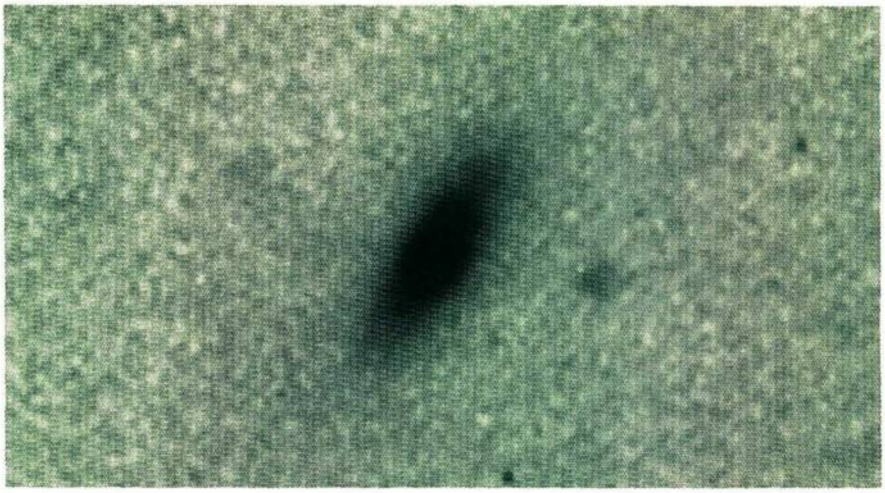
by a faint, diffuse halo of light. Astronomers eventually concluded that BL Lac was actually a highly luminous elliptical galaxy a billion light-years away; roughly 40 similar objects are now known.

BL Lacs emit radiation over all wavelengths, with rapid and large variations. Their visible light spectrum is featureless and the light is strongly polarized. Astronomers think the objects' radiation comes from jets of electrons aimed straight toward us and traveling at nearly the speed of light. The best hypothesis has been that BL Lacs and radio galaxies are basically the same objects, but viewed from different angles. However, up until now, BL Lacs and energetic radio galaxies had been found only in elliptical galaxies.



BRIGHT NUCLEUS, ELONGATED DISK: a newly discovered BL Lac object, PKS 1413+135, shines out of a galaxy with a disk (which appears oval due to perspective). No BL Lac has ever before been seen in this kind of galaxy. Image taken with the 4.2-meter William Herschel Telescope; courtesy Ian McHardy, Southampton University.

Space News

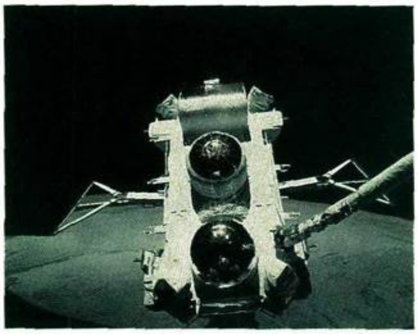
SUCCESSFUL LAUNCH FOR GRO

The highlight of 1991's first space shuttle mission was the launch of the Gamma Ray Observatory (GRO), a sophisticated astronomical observatory designed to study the universe in gamma rays. (See "An Eye on the Violent Universe," page 44.) The mission generated more than the usual excitement because astronauts undertook an emergency spacewalk to deploy a stuck antenna on the spacecraft.

NASA launched Atlantis mission STS-37 from the Kennedy Space Center on April 5 at 9:23 a.m. EST, following one of the smoothest countdowns in the history of the shuttle program. Marginal visibility near the KSC runway, where the shuttle would have to return in an emergency, delayed the launch five minutes. Aboard Atlantis were commander Steven Nagel, pilot Kenneth Cameron, and mission specialists Linda Godwin, Jay Apt, and Jerry Ross.

The first two days in orbit were spent checking out GRO and its subsystems. The actual deployment began on day 3, when Godwin grappled the satellite with the Remote Manipulator System (RMS) arm and lifted it out of the cargo bay. With GRO affixed to the arm and clear of Atlantis, its two solar panels were unfolded and they started recharging the observatory's internal batteries.

The mission went as planned until GRO's high gain antenna wouldn't budge from its stowed position against the side of the observatory. The antenna is the primary communications link with GRO, relaying data through NASA's Tracking and Data Relay Satellites in geostationary orbit to the ground.



Attempts to deploy the antenna by radio command failed to produce any motion. Further attempts to free the antenna while "jiggling" the observatory, first by rocking the shuttle with the attitude control thrusters and then by shaking the RMS arm, also failed.

With no other options available, Ross and Apt made an unplanned spacewalk, the first spacewalk for Americans since 1985. The astronauts' training paid off — 17 minutes after entering the cargo bay, Ross (tethered to the shuttle) climbed aboard GRO and shook the antenna free.

Ross and Apt then stayed outside for over four and a half hours in case any further problems developed on the observatory. While GRO continued its pre-deployment checkout at the end of the RMS arm, they started on work scheduled for a planned spacewalk the next day.

With GRO in good health, Godwin released the spacecraft from the RMS arm at 5:35 p.m. CDT on April 7, while Atlantis was over the Pacific Ocean. An analysis made after the antenna repair indicated that thermal insulation on GRO's antenna boom had probably shaken loose during the vibration of launch and snagged on the observatory, keeping the boom stuck in the stowed position.

The fourth day of STS-37 saw Ross and Apt make a planned, 6 hour 11 minute spacewalk to evaluate new equipment designs that will be used by the astronauts who construct the space station. Atlantis also flew several secondary payloads, including a crystal growth experiment, the shuttle amateur radio experiment, and a test of visual rendezvous techniques.

After a one-day delay due to high crosswinds, Atlantis landed at 6:56 a.m. PDT on April 11 on runway 33 at Edwards Air Force Base in California. The nearly six-day mission returned NASA to space after a four-month delay, but more importantly launched a new observatory destined to revolutionize our knowledge of the violent universe. — *Sean Sullivan*

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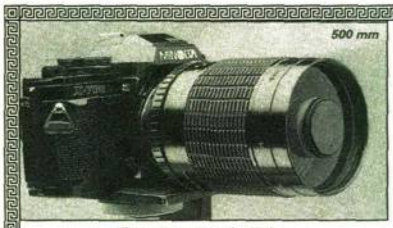

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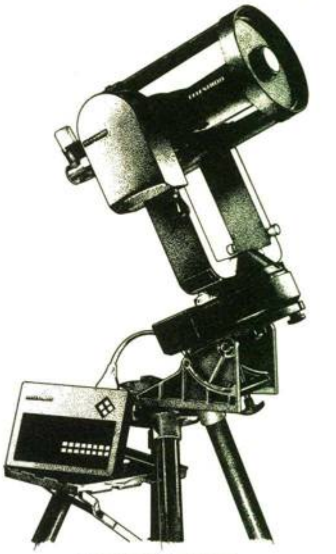

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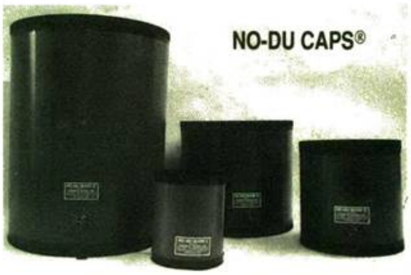

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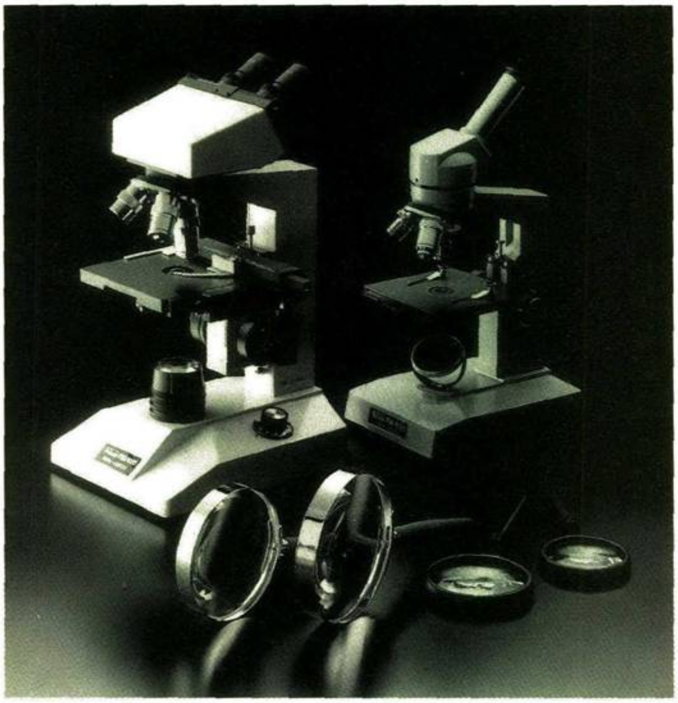

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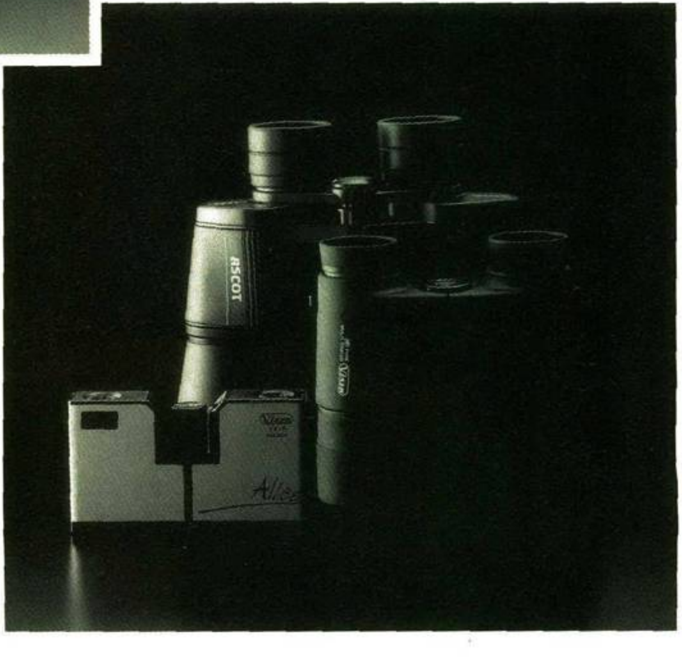

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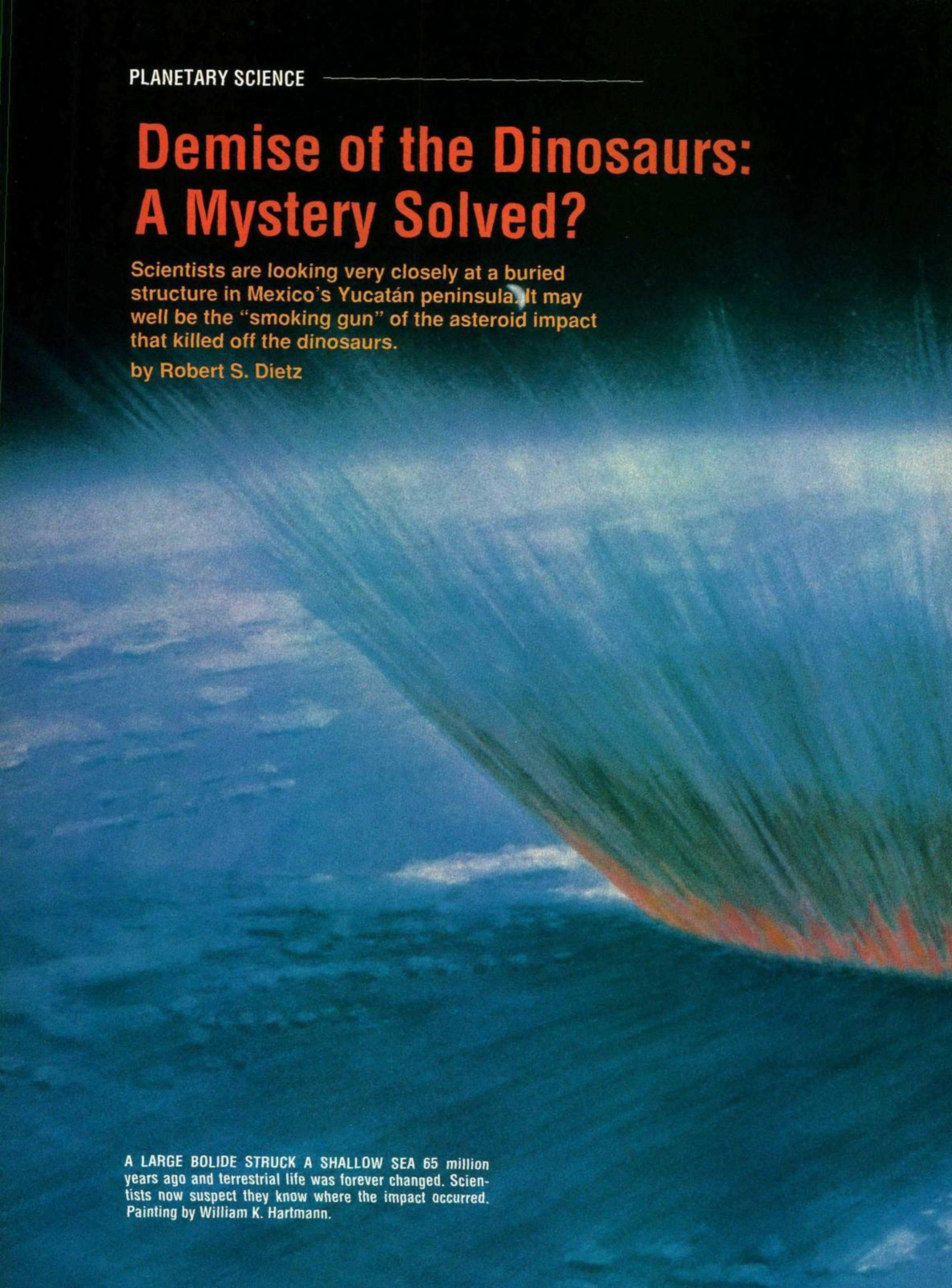
PLANETARY SCIENCE

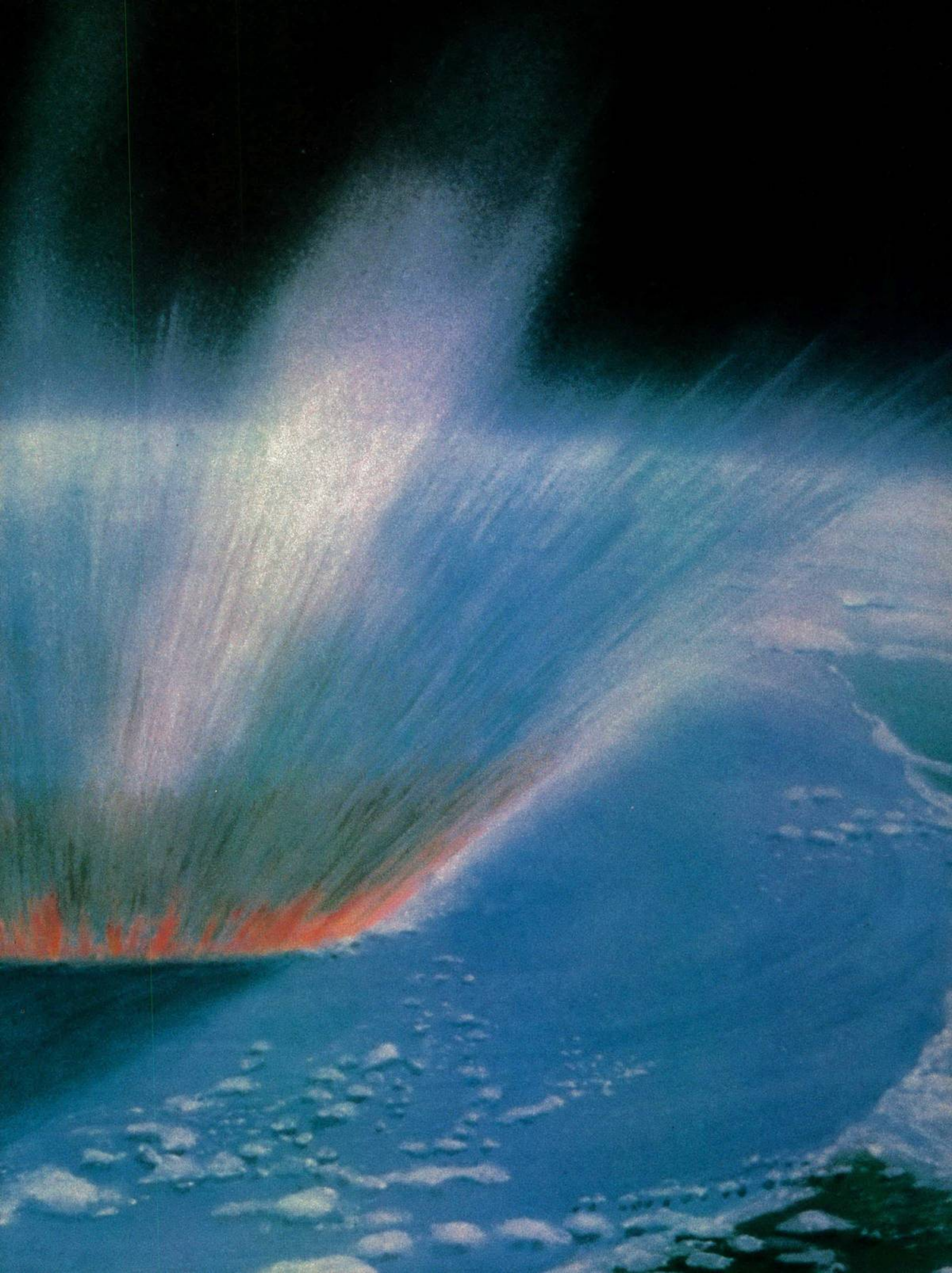
Demise of the Dinosaurs: A Mystery Solved?

Scientists are looking very closely at a buried structure in Mexico's Yucatán peninsula. It may well be the "smoking gun" of the asteroid impact that killed off the dinosaurs.

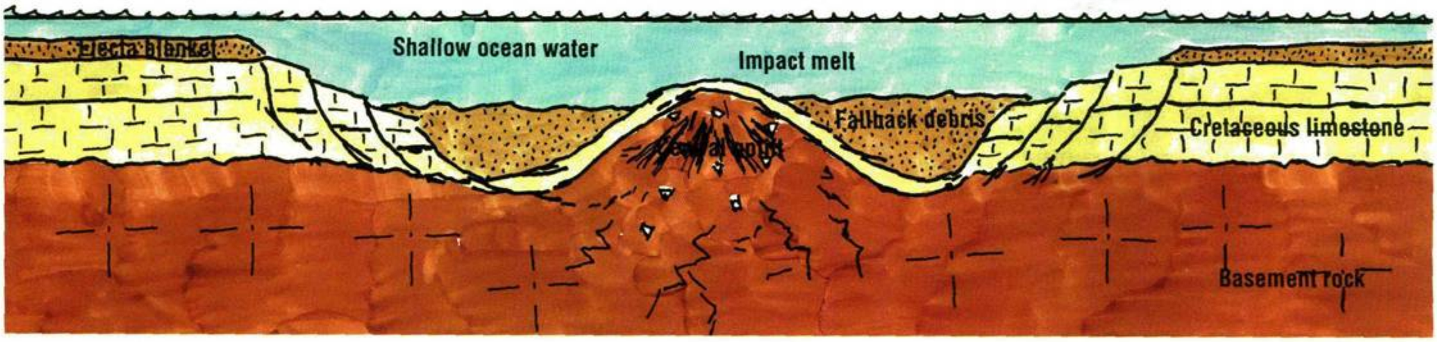
by Robert S. Dietz



A LARGE BOLIDE STRUCK A SHALLOW SEA 65 million years ago and terrestrial life was forever changed. Scientists now suspect they know where the impact occurred. Painting by William K. Hartmann.



How to Hide a Giant Crater



ABOUT 200 KILOMETERS ACROSS, the crater at Chicxulub, Yucatán, has a complex structure. This sketch depicts what it may have looked like right after the impact (above) and today (opposite page). Diagram by Patti L. Keipe, after R. S. Dietz.

A geophysical "timebomb," first unearthed over a decade ago, has finally exploded. The result is a great commotion among planetary scientists because it appears the "bomb" may pinpoint where an asteroid struck 65 million years ago, causing mass extinctions among the dinosaurs and many other forms of life. And, by a wonderful irony, the data causing the uproar were collected *two years* before anyone even knew there was a mystery afoot.

Death From the Skies

The story begins in 1980 when a team led by Luis and Walter Alvarez of the University of California-Berkeley startled scientists by proposing that a large meteorite impact was responsible for the demise of the dinosaurs, an event which marked the end of the Cretaceous period and the start of the Tertiary.

Although highly controversial, the impact hypothesis offered a neat solution to several geological problems. Besides providing a mechanism for the mass extinctions, it also explained the origin of a layer of clay fallout, extra-rich in the element iridium, that is found at more than 100 locations around the world. Iridium is thousands of times more abundant in primitive meteorites than in terrestrial rocks.

In the Alvarez scenario, a 10-kilometer-diameter "bolide" — an errant asteroid or comet — struck Earth and blasted an enormous cloud of iridium-laden dust high into the atmosphere, where it formed a dense pall that shut off sunlight for weeks or months. Acid rain, wildfires, and other noxious effects would also come in the impact's wake.

As scientists developed and tested the hypothesis, the nature of the bolide posed a problem. Two kinds of object are known to wander the solar system and could possibly strike our planet: a stony or iron-rich asteroid or a comet with a large rocky component, perhaps a burnt-out nucleus. The clay-layer evidence was *not too choosy:* amino acids have been detected in the impact clay at Stevns Klint in Denmark and in Alberta. While this points toward a comet (which are thought to contain amino acids), the samples may have been contaminated. It is also possible that the chemistry of asteroids is stranger than we know at present.

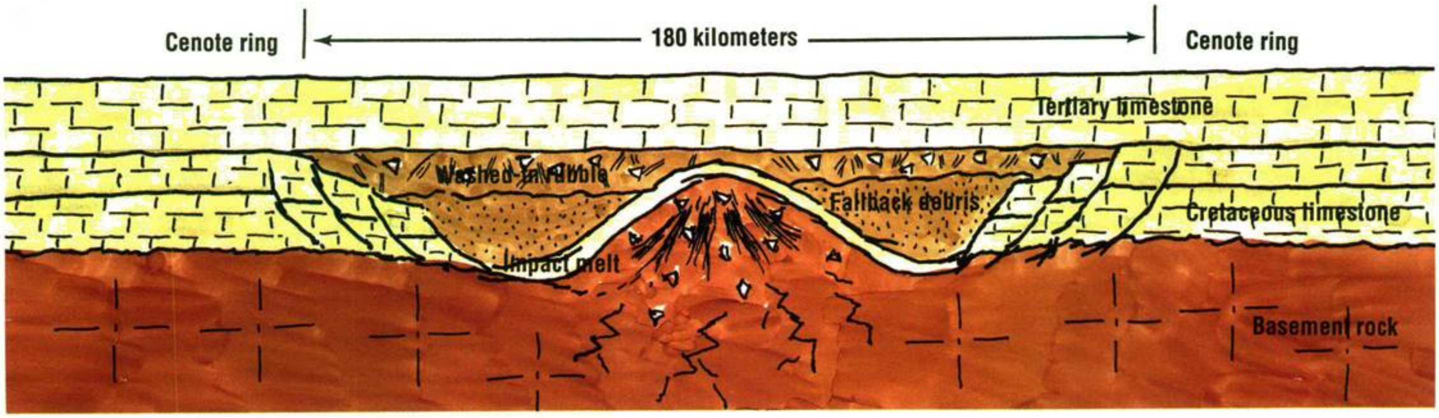
Looking for Ground Zero

Paralleling the searches for the thin layer of iridium-laced clay has been a search for the impact site. Craters are plentiful on the Moon, Mercury, and Mars. But on Earth they are rare because erosion and tectonic movements work to destroy craters quickly, turning them into what are called astroblemes ("star wounds"). These outnumber the relatively fresh meteorite craters nearly tenfold.

In explaining the cumulative volume of debris and its extra iridium, the Alvarez hypothesis called for a 10-kilometer-wide object striking at about 15 kilometers per second. The force of this impact would blast a crater 150 to 200 kilometers across. Because of its size, this crater would not be a simple bowl like Arizona's Meteor Crater or the small lunar ones visible in backyard telescopes. Instead, the crater would have a more complex form (see the cross-section above) perhaps resembling the lunar crater Copernicus. A central dome (created by the elastic rebound of the target rock) would be surrounded by rings of slumped-down wall material. In fact, apart from its circular shape, the crater from the "killer asteroid" might not look very much like a classic crater at all.

But finding a plausible candidate has proven difficult despite the fact that nature has a hard time destroying *all* traces of a crater. Over the ages cosmic cannonballs have struck Earth many thousands of times, blasting giant craters and basins. An impact takes seconds to happen, but its effects linger for billions of years. (Ontario's Sudbury Basin is 2 billion years old and still shows clear impact features.) Perhaps, as some scientists have proposed, we should not look for a single giant crater — the event may have resulted from a shower of bolides, a worldwide blast from the cosmic shotgun. For example, asteroid 1989 PB is known to be a dumbbell-shaped double object whose two bodies touch. Such an object would likely separate before impact into at least two projectiles, creating a pair of side-by-side astroblemes. Several examples of this are known, such as the East and West Clearwater Lakes in Quebec.

Yet the event that killed the dinosaurs differs from previous craters and astroblemes because scientists found the ejecta blanket and the debris before they identified a crater. Doesn't this weaken the case for impact? Not really. One estimate claims that geologists have discovered only 10 percent of the craters larger than 10 kilometers in diameter and less than 100 million years old. The Moon looks like a battered mess, but Earth should look worse because its impact flux is 10 times greater thanks to its larger size and



stronger gravity. Where have all the craters gone? They have been eroded by wind, water, and ice, and by the tectonic kneading that destroys them thousands of times faster here than on the Moon.

Suspicious Places, Suspect Catastrophes

For a known astrobleme to become a suspect in the Case of the Missing Dinosaurs it must have the correct radiometric age: between 64 and 68 million years old, to allow for the uncertainties of such dating. There is no lack of such structures — but many fail a second test: they are too small to be sufficient by themselves.

The object, remember, must have blasted a crater at least 150 kilometers across. In 1986, C. Hartnady speculated that the 300-kilometer-wide Amiranti Basin deep beneath the Arabian Sea in the western Indian Ocean was the site of the great extinction impact. He argued that the catastrophe reorganized the entire plate tectonic game plan and that the impact also triggered the extrusion of the vast Deccan plateau basalts of India, which are known to be 65 million years old. But reasoning from the thickness of the debris deposits, Glen Izett of the U. S. Geological Survey and others argued that the object must have struck in or near North America. This requirement initially focused interest on the Manson astrobleme in central Iowa, the largest in the United States.

Now completely buried beneath glacial debris from the Ice Ages, the Manson structure was detected by water-well drilling in the 1950s. Scientists originally described it as cryptovolcanic — created by a deep underground muffled explosion — but when they re-examined the drill cores in the 1960s they found telltale high-pressure shock effects in the rocks. These proved that Manson was an impact. With a radiometric date of 65 million years and a position near the North American fallout deposits, Manson seemed a prime suspect. Unfortunately, its 35-kilometer diameter shows that Manson is much too small to be the sole culprit, although it might possibly be one of several simultaneous impacts.

Astronomer Ralph Baldwin has pointed to still another suspect, an astrobleme he inferred to exist on the Parry Peninsula, along the arctic shore of Canada's Northwest Territories. A 1,000-foot-high arcuate scarp might be regarded as the southern margin of the disturbance of which the northern portion lies offshore. Convincing evidence that this is an astrobleme is lacking, however, because there is no sign of violent shocks in the central "eye" of the structure.

Focus On the Caribbean

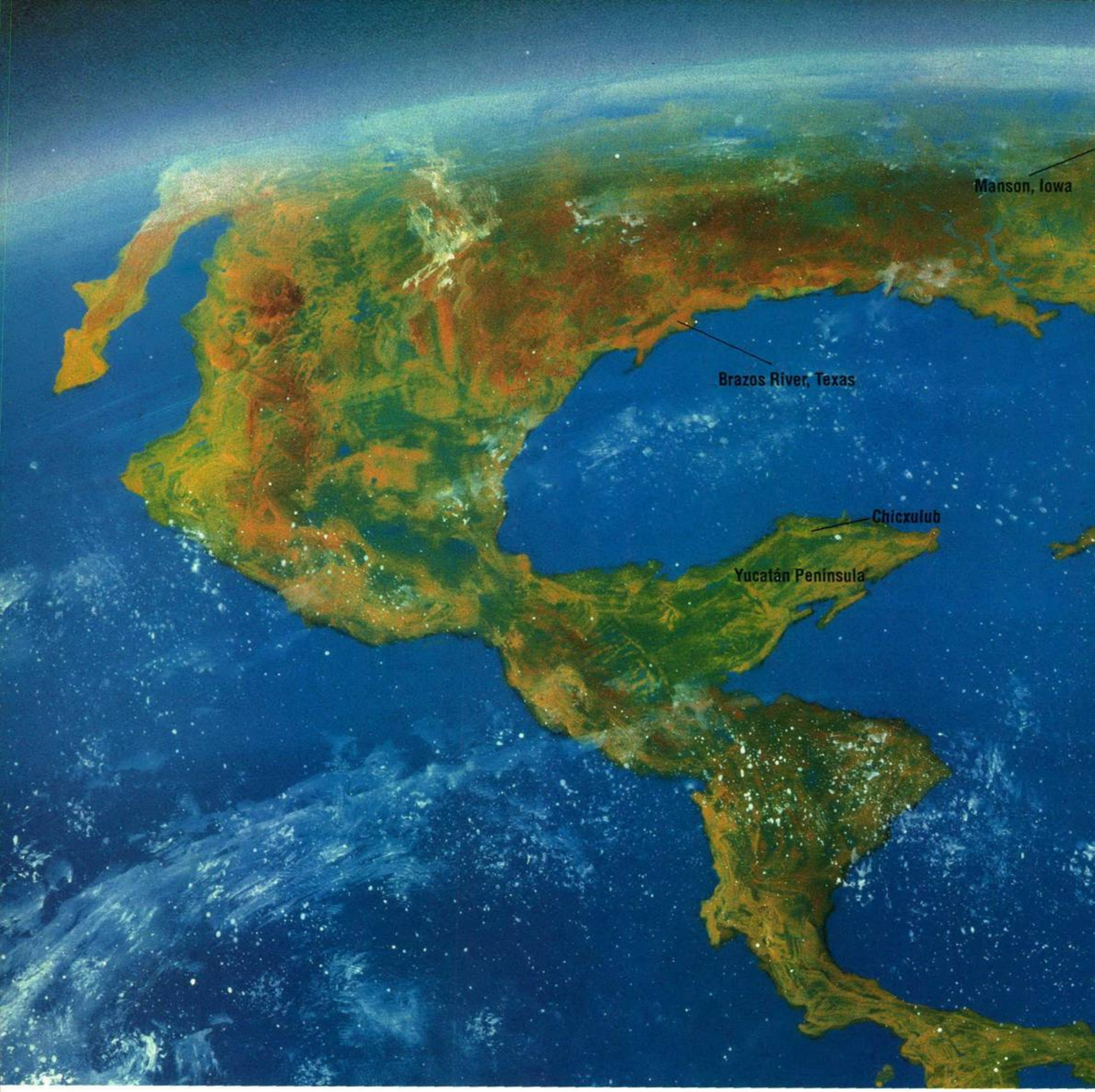
In 1988 interest shifted to the Caribbean region. Researchers found coarse rocky debris, interpreted as tsunami deposits laid down by giant waves spreading from a possible oceanic impact, at several sites on the U. S. Gulf Coast, notably in outcrops along the Brazos River in Texas. A little later, Alan Hildebrand of the University of Arizona and his colleagues examined sea-bottom seismic profiles and core samples and suggested that ground zero might be a 1,000-mile-wide depression in the Colombia Basin in the deep Caribbean north of Colombia.

The search intensified when Florentin Maurrasse of Florida International University discovered an 18-inch-thick layer of fallout debris in Haiti, with pea-sized clayey spherules which he identified as weathered tektites. Tektites are small blobs of glassy rock, aerodynamically molded into spheres, ovoids, tear drops, and dumbbells. Often found near a crater, they form from melted rock ejected during the impact and differ markedly from volcanic glass in their chemical makeup. In November 1990 Glen Izett of the U. S.G.S. confirmed Maurrasse's specimens were bona fide tektites by discovering within them unweathered cores of glass which he was able to determine were 65 million years old. (Izett also effectively ruled out the Colombian Basin site by showing that the content of the tektite glass and that of the fallout layers indicated the target rocks were continental, rather than oceanic.)

Recently, more studies of tektites from Beloc, Haiti, have ruled out any chance the glass was volcanic, which some hold-out geologists have been insisting was an open issue. A group headed by Haraldur Sigurdsson of the University of Rhode Island has shown conclusively that the glass contains no water or gas, which any volcanic-origin glass must have.

Another candidate site emerged in early 1990. Bruce Bohor of the U. S.G.S. and Russell Seitz of the Massachusetts Institute of Technology proposed, on the basis of published literature (but without visting the site), that Cuba's 40-kilometer-diameter Isle of Pines might be the site of the killer impact. They proposed that this generally circular island was the central uplift of an astrobleme stretching some 150 kilometers across. The idea seemed reasonable, so in June 1990 John McHone and I took advantage of a chance to visit Cuba. We couldn't visit the Isle of Pines (it was once a maximum-security prison!), but we were able to examine critical rock samples in Cuban geological laboratories.

From the samples we found the island is composed mostly of normal



rocks showing no evidence of intense shocks, either at the macro- or the micro-scale. Nor did we see any of the peripheral effects that such a giant impact would have left on mainland Cuba adjacent to the Isle of Pines. Therefore, we concluded that the Isle of Pines cannot be the remnant of a giant impact crater.

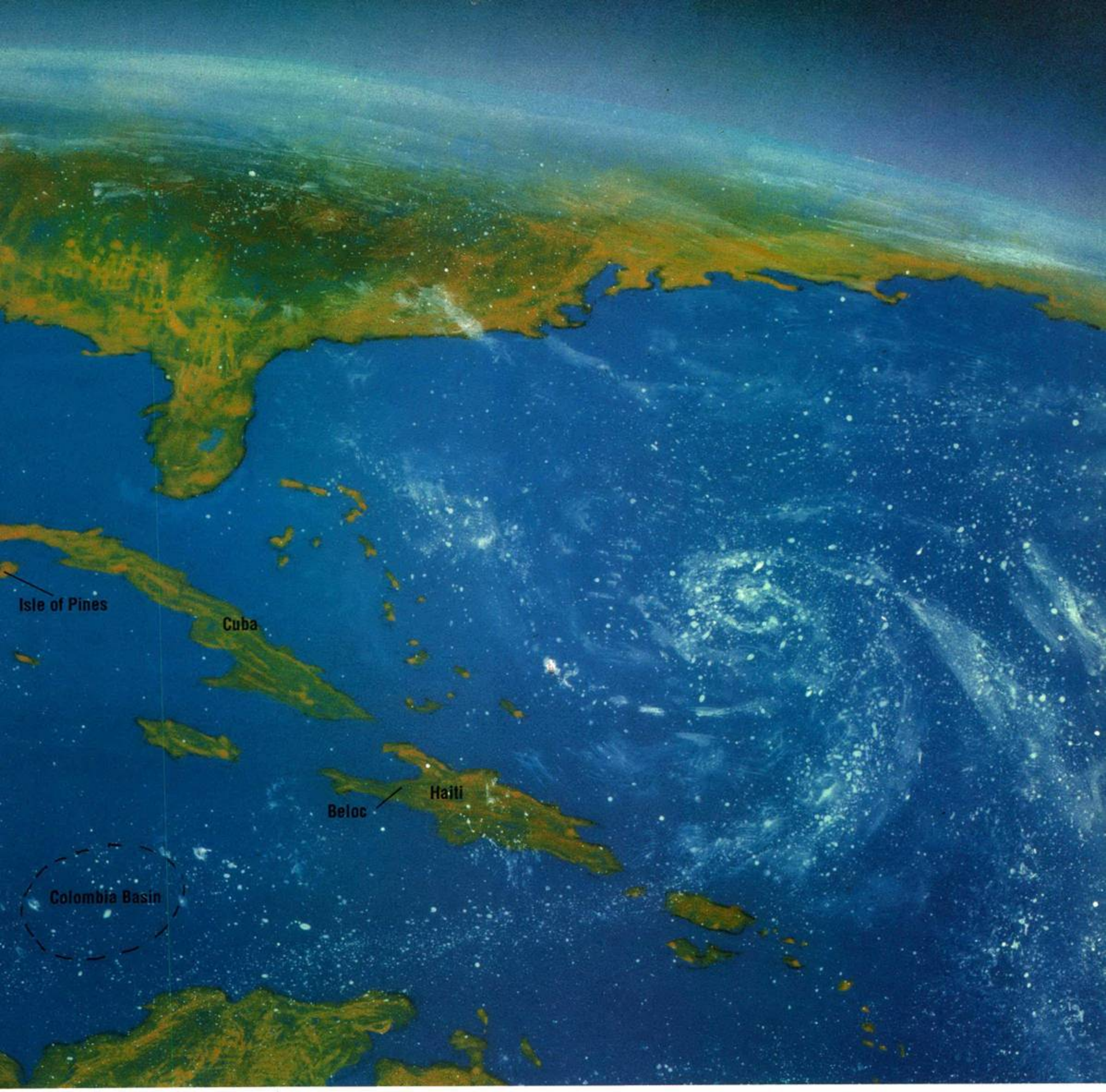
Chicxulub: Tail of the Devil

The crazy thing is, while dozens of planetary scientists were spending a decade looking here and there for shocks, ejecta blankets, and impact structures, a far more likely location for the site was already "in the can."

The story of this geophysical time-bomb begins back in the spring of 1978 when Pemex, Mexico's national oil company, began an aerial magnetic survey off the northern coast of the state of Yucatán. Towing a magnetometer behind an airplane is a rapid means of roughly assessing the thickness of sedimentary — and possible oil-bearing — rocks in a given area. Beginning hundreds of kilometers offshore, the Pemex survey traced a grid pattern over the warm, shallow waters of the Caribbean north of the Yucatán coast.

"Soon after the survey began, I started to see an extraordinary pattern on a huge scale," says Glen Penfield, then a geophysicist recently out of Oberlin College. It was his job to examine daily the 15-foot-long charts from each 1,000-kilometer aerial traverse.

"First, I saw one little patch of magnetic disturbance in an east-west traverse. I didn't think anything of it. On the next day's traverse, running parallel and 5 kilometers south, it was in the same place but wider. On the third day's traverse it broke in two. Thereafter, a double distur-



LAND OF SUN, SURF — AND IMPACTS? The Caribbean Sea and lands surrounding it contain many of the sites where scientists have found key evidence for a massive impact at the end of the Cretaceous period, 65 million years ago. Painting by Michael Carroll .

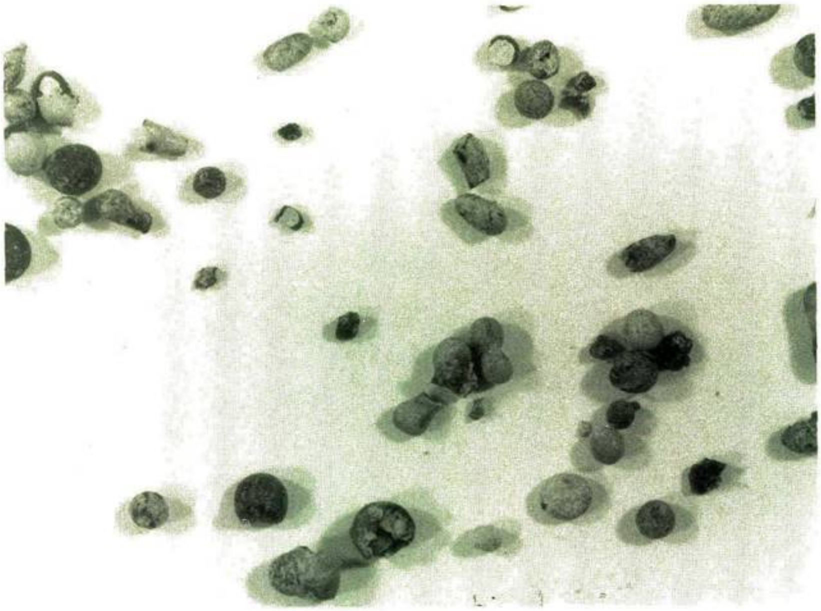
bance always occurred symmetrically placed around a north-south line, even though the locations grew farther apart on each traverse.

"When the aerial survey had nearly reached the Yucatán shore, the two separate disturbances were about 120 kilometers apart. At that point I suddenly began to see big magnetic anomalies in the center — chart deflections showing a disturbance with 5 percent the strength of the Earth's magnetic field. These indicated the presence of something *very* magnetic. After a month and a half — I'd been hand-plotting the data on a chart in my office — I had half of a huge bull's eye staring me in the face."

When Pemex finished the over-water part of the reconnaissance and began on shore, Penfield located a detailed gravity survey from decades before. The gravity map showed a ring structure on land that neatly mated with the offshore ring of magnetic anomalies.

"When I saw that," Pennfield says, "something flashed on me. I looked at the symmetry and just knew I was seeing a buried impact crater."

Penfield and his colleague Antonio Camargo wrote up the results of the aerial surveys, including a speculation that this was an impact crater site, and announced the findings at the 1981 annual meeting of the Society of Exploration Geophysicists.



TINY SPHERES OF GLASS, these tektites found in Haiti are condensed from rock melted in the violence of impact. Photo by F. Maurrasse.

What was the earthshaking result? Nothing! The discovery went completely unnoticed by everyone who was hunting the killer impact site. The problem was that few planetary scientists go to meetings of oil-exploration scientists.

Penfield's next thought was to wonder if anyone had drilled in the region where the buried structure lay. The answer was yes. Pemex had sunk land wells in the area in the early 1950s, but without striking oil or gas. The company's field work did establish, however, that the Yucatán platform was a flat sheet of limestone tilting very gently north. Laid down directly on top of a basement rock that was much older, the limestone dates from Cretaceous at the bottom to Tertiary at the top. This means the rock strata neatly span the time of the hypothetical impact (see the cross-section on page 33).

The Pemex well logs showed that as the drilling bored downward, it passed through about a kilometer of undisturbed limestone. Then it encountered a type of broken and shattered rock called breccia. From three of the wells, up came pieces of a rock that the company geologists identified as volcanic andesite. This suggested that there was a large intrusion of solidified magma squeezed into the sequence of Cretaceous and Tertiary limestones. These rocks were named the Mérida volcanics after a nearby town.

When Penfield checked on what had happened to the core samples, he found that the Pemex warehouse in which they were stored had suffered a fire and the samples were destroyed. "Everything was lost," he notes.

"I was desperate. I thought, if the moonrock people can work with little shards... Well, I went back out to the sites of the drill holes on my own, hoping that in the pile of discarded cuttings I could find samples of that volcanic rock. I suspected the andesite was either impact melt or the result of impact-induced volcanism. If I could find even a small piece — even after 30 years' exposure — I could test it for impact shock.

"But no luck. Lots of creamy-white limestone fragments but no dark andesites, despite my offers of substantial rewards. I took about 30 pounds of white rocks, just in case, and gave most of them to a friend at NASA. I kept about 10 pounds myself for a doorstop."

Today Penfield muses, "Are there shattered impact fragments in those chunks? Maybe. But my job was, and is, finding oil and I haven't the time or money to take them apart grain by grain to find out."

The 30 pounds of rocks Penfield took came from the well drilled at the village of Chicxulub (pronounced CHEEK-shoe-lube), a local Maya name meaning "tail of the devil."

Meanwhile, planetary scientist Alan Hildebrand and his colleagues at the University of Arizona had been hunting in the Caribbean for the impact site. They had already uncovered thick beds of ejecta in Haiti and proposed the (now rejected) Colombia Basin as the impact site. Last year, in his many contacts with other scientists, Hildebrand heard of Penfield and Camargo's finding; he also learned of the Pemex core samples and the catastrophic fire.

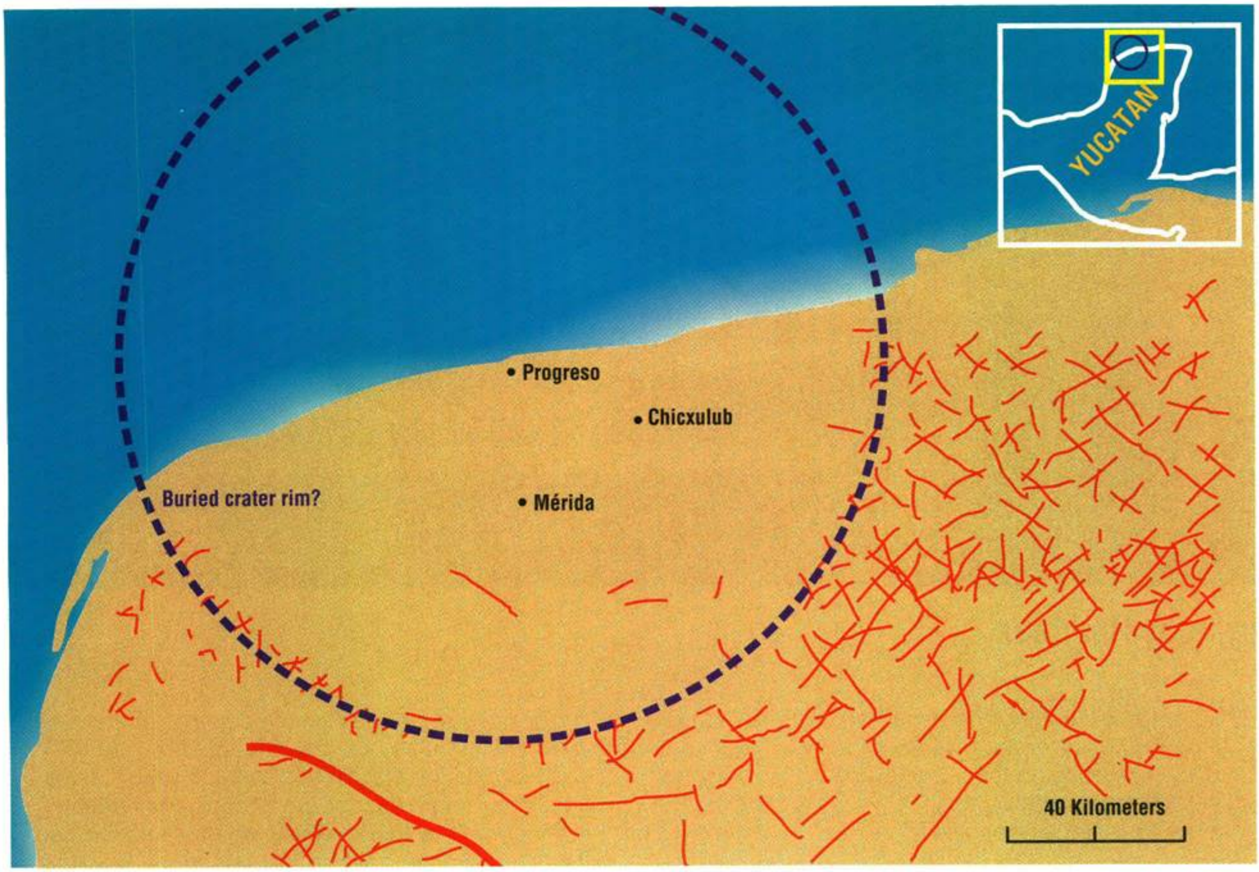
Although the cores had been lost, Penfield helped Hildebrand locate a few pieces of glassy melt rocks within a breccia that had been removed from the cores and sent to a geologist in the United States. From them Hildebrand and his colleagues have reported the presence of highly shocked quartz. This would indicate the rock is an impact microbreccia. This finding, however, remains somewhat uncertain at the moment because another planetary geologist with similar samples has been unable to confirm their findings. Verdict? Not proven — yet.

Ruins, Water, a Crater

Northern Yucatán is today a flat, semi-arid expanse with a brushy, savannah-like vegetation. There are no streams, rivers, or lakes at the surface: any rainfall quickly percolates into the limestone, gently dissolving it along cracks in the rock. Where you do find water, it is in a cenote (seh-NOH-tay), an open, collapsed sinkhole filled with groundwater. Because cenotes offered easy access to potable water, Mayan archaeological sites cluster around them. In fact, a plot of the ruins is essentially a plot of the cenotes.

Using Landsat imagery, Kevin Pope of Geo Eco Arc Research and his collaborators, including Luis Marín of the Mexican National University, used the placement of the cenotes to make a remarkable discovery that strongly supports the idea that an ancient impact crater lies buried deep below Chicxulub. When Pope and his coworkers mapped the faults, joints, and cenotes in the Yucatán limestone, they found that the faults avoided a region that forms a 170-kilometer-wide semicircle (see map opposite). Bordering the semicircle is a region with an unusually high number of cenotes long known locally as the zone of the *chenes,* which is the Maya word for sinkholes. This ring basically outlines the crater's buried southern rim, while the northern half of the structure — outlined by the magnetic anomalies — presumably lies offshore.

What caused the cenote ring? After impact the fresh crater would have been quickly filled to the brim with washed-in debris. Over time, this would compact as the shallow



THE GHOST CRATER OF YUCATÁN shows its buried rim by the way it controls the goundwater flow and the related joints and fractures at the surface. Diagram by Thomas L. Hunt, after K. O. Pope.

ocean laid down on top of them the layers of limestone that now make up the Yucatán. Inside the crater the ground may have subsided farther after the limestone was deposited. This would have cracked the rock that lay directly over the rim, allowing groundwater to etch the band of cenotes along the fractures.

Groundwater drainage is so well developed in the Yucatán that water levels within cenotes are generally less than a meter above sea level and even damped tidal fluctuations have been recorded. The ring is so precisely circular that it must reflect a force impressed directly from above or below. The cenote ring also coincides exactly with the magnetic and gravity anomalies.

But what about the age of the Chicxulub structure? How closely does it fit the 65 million year date? "The Pemex geological report, based on the cores, got the age wrong," says Penfield. "The geologists dated the Mérida volcanics to the upper Cretaceous — they made the crater too old.

"But if this thing *is* an impact crater, think about the sequence of events for a moment. You'd have this 9-kilometer-deep hole in the ground, and it's entirely believable that lots of Cretaceous chunks would fall in off the walls. If the well drilled down through that stuff, it would come up with an age-date misplaced in time."

Is Chicxulub the Crater?

The pieces of this decade-old puzzle may have finally fallen into place. The crisis for Earthly life at the end of the Cretaceous, when a pall fell over the planet like a nuclear winter, has long been evident. Sixty five million years ago extinction laid its hand on the ammonites, most kinds of plankton, and the dinosaurs, to name a few. Somehow a few small mammals survived. So also did great flightless birds, which dominated the scene at first but soon passed into oblivion, permitting the mammals to inherit their estate.

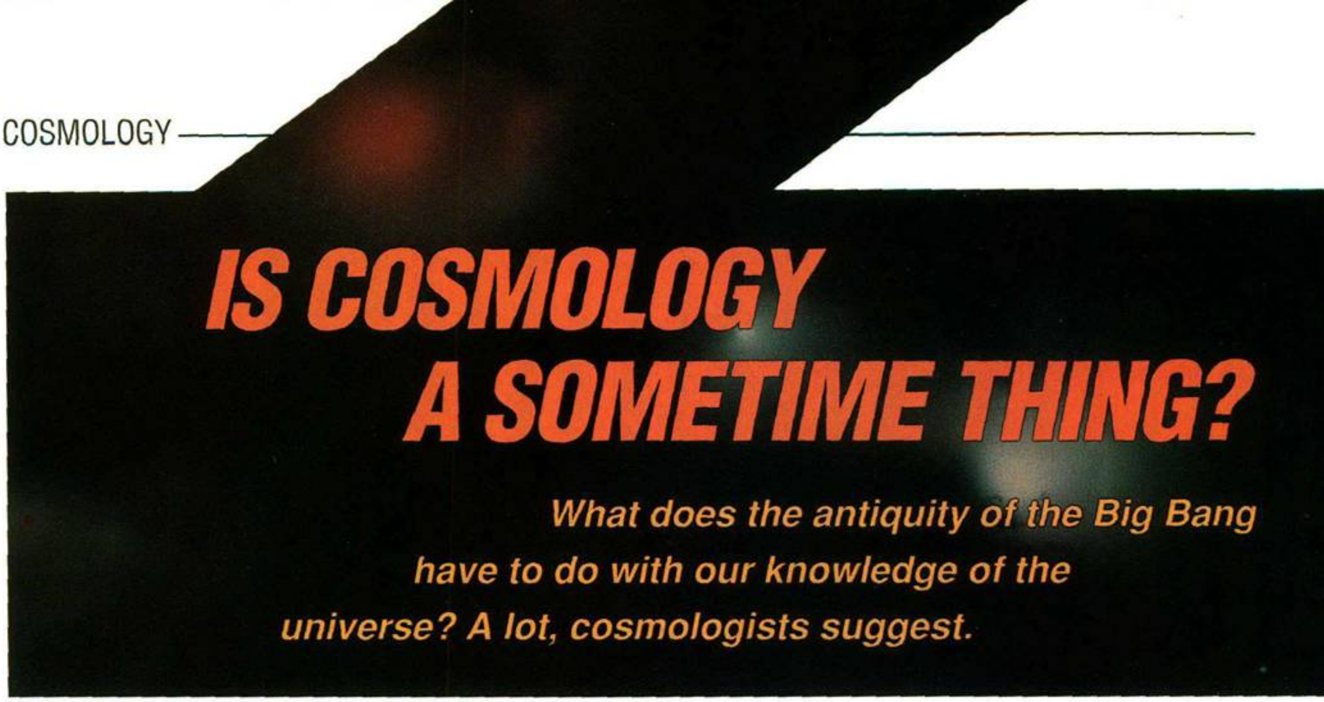
Over the past decade — and amid controversies, at times raucous — the work of thousands of scientists in hundreds of laboratories has pointed more and more directly at the reality of a great impact at the end of the Cretaceous. Its exact whereabouts have remained a major unknown. The answer to that question may now lie almost within reach. The Chicxulub feature is in the right place, of the right size, and apparently of the right structural style, with the right rocks, and of the right age to satisfy the constraints of evidence. The chances are excellent that the killer crater finally has been found.

So what's the next step?

"The next thing," says Glen Penfield, who is now working for Carson Services in Perkasie, Pennsylvania, "is for the 'friends of Chicxulub' to talk to the Mexican government. I think if the government feels this is an issue of national scientific interest, they'll approve a geophysical survey and drilling program that'll make the crater a Mecca for world impact studies.

"Just think of it — in places the crater rim is only about 400 meters down. . . ." □

Robert S. Dietz is an emeritus professor of geology at Arizona State Univesity. He identified a feature called shatterconing as a criterion for identifying the sites of ancient terrestrial impacts. In 1985, he received the Barringer Medal for his research on meteorite craters and astroblemes.



IS COSMOLOGY A SOMETIME THING?

What does the antiquity of the Big Bang have to do with our knowledge of the universe? A lot, cosmologists suggest.

by Tony Rothman

Good science-fiction writers know that the settings they choose for their stories will exert considerable influence on them. For example, invoking a planet with a much stronger gravity than Earth's might give rise to characters with short, stocky bodies and powerful arms and legs. Perhaps on such a world flying machines would develop slowly — or not at all. Or if the fictional planet, like Venus, were perpetually enshrouded by clouds, its inhabitants might walk with their heads to the ground and astrology would never develop — a blessing, to be sure — but neither would astronomy.

You must be careful when you design planets or futures. On a cloud-covered world, tides might exist and consequently its inhabitants could, with difficulty, deduce the presence of any moons and suns. Once technology had progressed far enough, radio and gamma-ray astronomy would become possible (because clouds are transparent at these frequencies), but discoveries would probably be accidental, since no one would be scanning the skies to begin with. So a cloud-blinkered civilization could eventually embark on astronomy, but the picture of the universe it arrived at would differ considerably from our own.

Thoughts like these prompted me to wonder at what stage in the universe's history a science of cosmology could develop. It turns out that the "epoch of observational cosmology" is *not* the same as the history of the universe until now; at certain times in the past, cosmology was difficult or impossible to study, and in the far future it will become impossible once more.

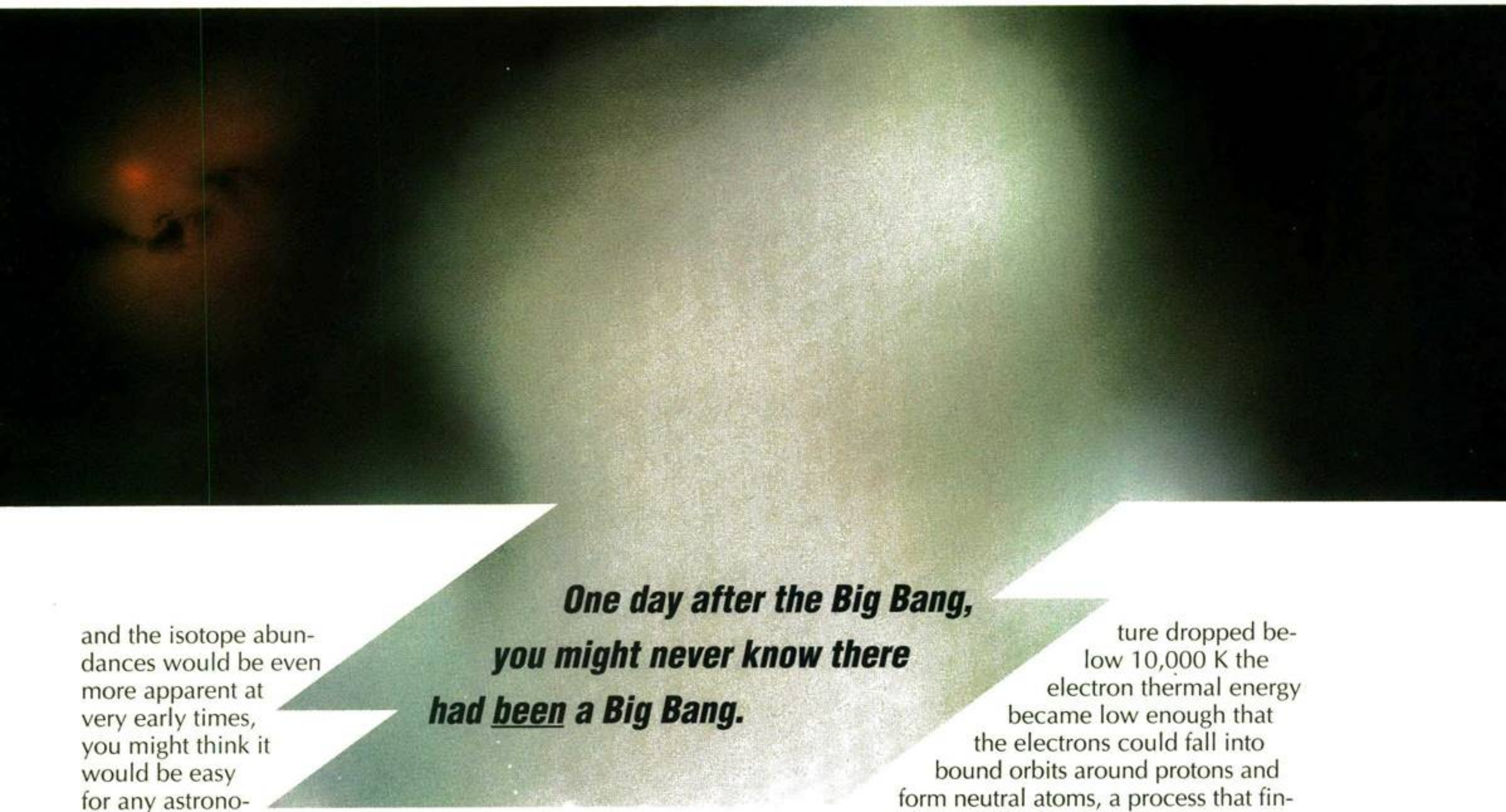
Early Times

Suppose you could observe the universe shortly after the Big Bang — "shortly" meaning from about 1 day to 100,000 years. What conclusions could you draw about your environment?

Not many. If you could build a thermometer, you could certainly deduce that the universe was expanding because the temperature would be dropping rapidly, along with the density and pressure. The universe's temperature is the temperature of the cosmic fireball radiation left over from the Big Bang itself — the same radiation that 10 to 20 billion years later is termed the cosmic microwave background radiation and is observed at 2.7 kelvins. One day after the Big Bang the temperature was about 30 million K and halving roughly every four days thereafter. The fact that the temperature was so high means that this radiation would not be observed as microwaves (which are relatively cold bundles of energy, or photons) but as soft x rays (relatively hot photons).

Apart from this radiation, the only matter in the universe would be some protons, deuterium, and helium — the light isotopes believed to have been formed in the first three minutes after the Big Bang. That period was a time when the temperature was high enough to support the nuclear reactions that could process neutrons and protons into heavier isotopes, and yet cold enough that the newly formed elements would not immediately break up again into the constituent protons and neutrons. This primordial nucleosynthesis processed about 25 percent of the universe's mass into the common form of helium, helium-4. A tiny fraction — about 1/100,000 — is in deuterium, and similarly small trace abundances are found of other light isotopes such as helium-3 and lithium. The overwhelming majority of the universe's mass — the remaining 75 percent — is taken up by unprocessed hydrogen nuclei: protons.

The existence of the cosmic background radiation and the primordial isotope abundances are in fact the key pieces of evidence that present-day cosmologists use in favor of the Big Bang. Without them such a model would be difficult to substantiate, yet it appears to be correct in its main features. The Cosmic Background Explorer satellite verified in 1989 that the background radiation has a blackbody spectrum, exactly the form predicted by the standard Big Bang model. Today it is very hard to conceive of any explanation for the cosmic background radiation other than the Big Bang, and given that both the background radiation



One day after the Big Bang, you might never know there had been a Big Bang.

and the isotope abundances would be even more apparent at very early times, you might think it would be easy for any astronomer back then to establish a Big Bang theory.

Actually, no. Observing anything then would have been difficult since galaxies, stars, and planets would not yet exist. Furthermore, at these high temperatures the density of x-ray photons would be so great that they could not travel very far before colliding. At 30 million kelvins, the so-called mean free path of a photon would be only 100 to 1,000 kilometers. So while intelligent beings might establish a Big Bang model, their concept of the universe would be rather limited — in fact, to a sphere roughly 1,000 kilometers in radius! Anything beyond this distance would be unobservable unless they developed neutrino astronomy. Neutrinos are small, light particles that collide only rarely with themselves and with other particles. In fact, by the time the universe is one second old, neutrinos will have essentially stopped interacting with anything. Thus if our astronomers could somehow collect neutrinos, they could gather information from distant parts of the universe. However, this would be no easy task. Since neutrinos dislike interacting with other matter, neutrino detectors are extraordinarily difficult to build. Indeed, neutrino astronomy exists only in the most primitive form today; detection of neutrinos from supernova 1987A was its first major success.

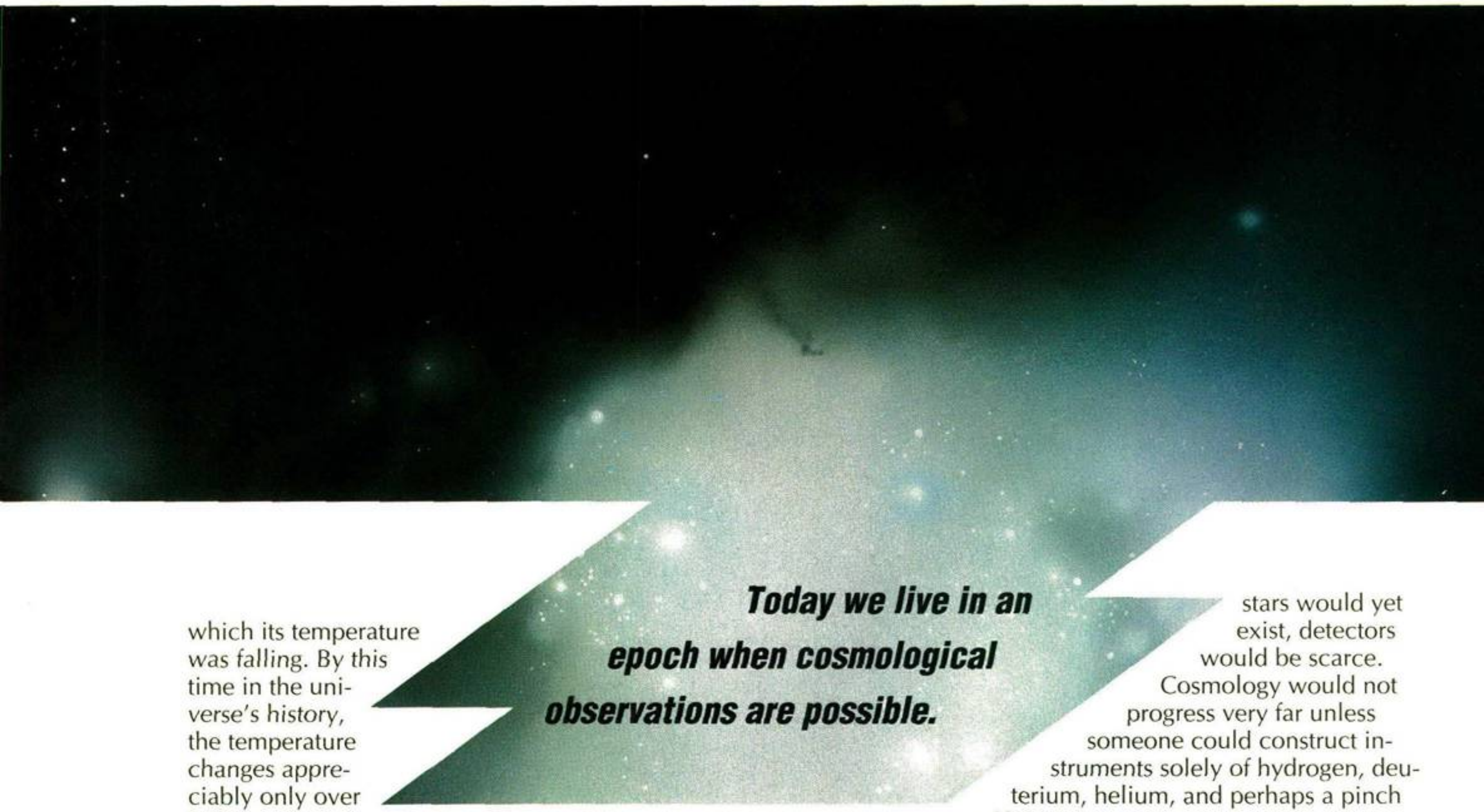
At 100,000 years after the Big Bang, the situation becomes slightly more encouraging. Prior to this time the universe was so hot that the thermal energy of electrons exceeded the strength of the electrical attraction between electrons and protons. As a result, electrons were moving too fast to be bound with protons into atoms. They remained separate and so the primordial soup was highly ionized. But when the temperature dropped below 10,000 K the electron thermal energy became low enough that the electrons could fall into bound orbits around protons and form neutral atoms, a process that finished by about 4,000 K.

It turns out that neutral atoms do not scatter photons as well as ionized atoms, and so at this point the universe suddenly becomes transparent to light. But there is still nothing to see. At 100,000 years after the Big Bang, the first perturbations in the primordial gas that will eventually become galaxies are just stirring. Though astronomy might be possible, it would not be very exciting because it would still have little to look at.

The situation becomes marginally less dismal when the temperature drops to about 10 kelvins, or when the observable universe is roughly a billion years old and about one-fifth its size today. It's unlikely that any sort of life could exist, because planets would not have formed and perhaps not even galaxies or the earliest stars, known to astronomers as Population III. The oldest quasar yet found dates from about this period and astronomers do not expect to find a great many older ones.

Thus even if life could somehow exist, there would be very little to observe. However, the most important drawback for observational cosmologists is that measuring the redshifts of quasars or galaxies would be impossible. Light from an object moving toward us becomes bluer; light from an object moving away from us becomes redder. The fact that most galaxies show redshifts is the major piece of evidence that the universe is expanding.

A universe one billion years old would be transparent to light, but because it would lack normal galaxies and have only a few quasars, the redshift clue to the Big Bang theory would be missing. Astronomers could measure the temperature of the background radiation, but they could no longer directly measure the rate at



Today we live in an epoch when cosmological observations are possible.

which its temperature was falling. By this time in the universe's history, the temperature changes appreciably only over billions of years. Since astronomers would see a constant temperature, only a lucky guess would tell them that the background radiation was left over from the Big Bang. In any case, at that time various processes creating galaxies could be generating so much energy that the background radiation might be masked.

The abundances of helium, deuterium, and the other light isotopes would perhaps be helpful. These isotopes, left over from the first three minutes, would not yet have been processed into stars and galaxies and would therefore be present in their original abundances. If cosmologists could simulate primordial nucleosynthesis in a computer, they would confirm that the standard Big Bang model produces the observed amounts of the isotopes. These would then be the best clue pointing to the Big Bang.

Would this have been enough to lead them to a Big Bang theory? A look to the early twentieth century makes you wonder. By that time galactic redshifts were measurable, but there was still considerable debate as to whether the universe was expanding. In the vastly more difficult circumstances of a one-billion-year-old universe, it seems doubtful that anyone could come up with a reasonable picture of the universe.

But as with our discussion of the first day after the Big Bang, the astronomers in this somewhat older universe are not very convincing. Life could probably not exist only one billion years after the Big Bang. But even if it could, to observe the cosmic background radiation or the isotope abundances (which is done by spectroscopy) requires detectors. Traditionally, detectors like telescopes or spectrometers are built from heavy elements, which are made in stars. Because few if any stars would yet exist, detectors would be scarce. Cosmology would not progress very far unless someone could construct instruments solely of hydrogen, deuterium, helium, and perhaps a pinch of lithium.

Late Times

Today, some ten billion years after the Big Bang, we live in an epoch of observational cosmology. We have heavy elements, we have detectors, and we have data about the distant universe, both long ago and far away. But how far into the future can we expect the present epoch of observational cosmology to extend?

The future for cosmology turns out to be more interesting than the past. Let's imagine for the moment that life will continue to exist into the indefinite future, and let's further imagine the universe will last about 300 billion years (about 20 to 30 times its present age) and will expand to about ten times as large.

Astronomers today know that star formation is slowing because the raw materials — principally hydrogen — are being depleted as new stars are made. Some estimates give only 5 billion years for half the remaining material to be exhausted. Therefore the universe may not be making stars 300 billion years from now, or at least not at a high rate. By then all of today's bright luminaries will have exploded or flickered out. The Sun will no longer shine, nor will any of the stars you see on a clear night. Nevertheless some of today's low-mass stars may continue to burn for another 100 trillion years, thanks to their parsimonious use of energy resources.

As the universe continues to expand, strangely enough, the redshift from a receding galaxy *decreases*. This surprising outcome results from the fact that the universe's rate of expansion is slowing down, so redshifts must decrease with time. At 300 billion years the galaxy is ten times farther away than it is now; its ap-

parent size is ten times smaller. The result is that the apparent brightness of a given galaxy will be at best 100 times less than it is now. But things may actually be worse because many stars will have ended their burning, and if star formation itself has ceased, a galaxy's luminosity will be even lower by factors of hundreds or thousands. The upshot of this is simple: galaxies that are easy to detect at present will become much more difficult to observe.

Because as time goes on, light reaches us from ever greater distances, more and more galaxies become observable as the universe ages. But such galaxies are ever farther away and older and so are dimmer and dimmer. Thus, even though more and more objects can be observed as the universe expands, they become harder and harder to detect. It is easy to imagine a time in the future when galaxies would be so dim that astronomers at our technological level would be unable to tell if the galaxies lay outside the Milky Way. In fact, they might term the faint patches nebulae, just as nineteenth-century terrestrial astronomers did before they realized the smudges were other galaxies like our own.

With distant galaxies so dim, their spectra would be difficult to obtain, and it might become impossible to determine galactic redshifts. Astronomers then would lack the key piece of evidence that the universe is expanding. Quasars, thought to be violent, active galaxies in the early stages of their evolution, would presumably have vanished altogether, eliminating that piece of evidence that there *was* an early stage to the universe.

At some point, perhaps when the universe has expanded by another factor of ten, all galaxies not gravitationally bound to the Milky Way will have receded to the point where they have disappeared from view, leaving behind only those galaxies bound by gravity to ours and therefore not receding (that is, those galaxies in what is left of the Local Group, our immediate cluster). Astronomers might then conclude they live in a static island-universe, consisting of a relatively small number of galaxies. The history of cosmology, in which some of the earliest models were static island-universes, shows that this is a very natural assumption to make.

What about the cosmic microwave background? Could an astronomer 300 billion years from now measure it? First, the temperature of the background radiation would have fallen to 0.27 kelvins from its current 2.7 K. The lower temperature is about the size of the error in the 1989 satellite measurements, so an accidental discovery with the primitive equipment of 1965 (when Arno Penzias and Robert Wilson stumbled onto the radiation) would seem unlikely. Furthermore, the factor of ten decrease in temperature means that the frequency at which the radiation is detected (now in the microwave region) would also have fallen by a factor of ten and that the intensity of the radiation would have fallen by a factor of 1,000. The thousandfold decrease in intensity implies that in order to detect the background, a receiver would have to be 1,000 times more sensitive than those used today. That would be a challenge. But in any case, when the background's peak frequency dropped by a factor of ten, it would be radiating at the same frequency as dust in the Milky Way, so there would be almost no reason to suspect that the signal came from the Big Bang at all.

Given that galactic redshift data would at best be poor and perhaps nonexistent and that the microwave background might never be discovered, it seems plausible that cosmologists living 300 billion years from now might never posit a Big Bang theory. Rather, they might conclude they lived in a static island-universe.

What about the isotope abundances, the durable fossils of previous chemical eras? No go here, either. By this time all the original abundances would be wiped out — the helium, deuterium, and lithium produced by the Big Bang and measured today would have been incorporated into stars and reprocessed into heavier elements. Then, as stars became supernovae, the new mix would have been scattered into space. This recycling would happen not just once in 300 billion years but probably a dozen times. If future cosmologists computed, as we have, the abundances resulting from the standard Big Bang model, they would calculate that about 1/100,000 of the mass of the universe should be concentrated in deuterium. But observations would

300 billion years from now Big Bang cosmology would be like religion — something you accept on faith.

refute this: thanks to stellar recycling, future astronomers would find no deuterium whatsoever.

How would cosmologists account for the isotope abundances that were measured? The history of cosmology, before the current Hot Big Bang model won out over its competitors, provides many alternative explanations. Especially popular some years ago were the so-called Cold Big Bang models, in which the universe started out as pure hydrogen at a temperature of absolute zero. Gradually the hydrogen condensed into stars, which subsequently underwent nuclear ignition. In these models the observed element abundances are solely the product of stellar nucleosynthesis. Traditionally, the problem with the Cold Big Bang models was predicting the correct element abundances without elaborate juggling of parameters (the Hot Big Bang accomplishes this fairly naturally). But in the far future, when primordial abundances will have been masked by stellar reprocessing, a cosmologist's only choice might be to invoke stellar astrophysics to account for the observations.

In late times problems would emerge not only with galactic redshifts, the cosmic background radiation, and the isotope abundances, but also with the entire thermodynamics of the universe. For instance, theorists have suggested that the second law of thermodynamics is a result of the Big Bang. The second law asserts, in brief, that the entropy of an isolated system must never decrease. (Entropy is a measure of how "run-down" a system is — the more entropy, the less work the system can do.) Indeed, as stars burn out and the material to make more of them is used up, the more the overall entropy of the universe seems to increase.

No generally accepted explanation for the second law exists. However, many cosmologists believe that if the Big Bang was a "zero-entropy" event, entropy — so to speak — had nowhere to go but up. Of course, if in the far future it is impossible to establish a Big Bang theory, such suggestions would never arise. The universe, which we now view as an uninterrupted cooling-off after the Big Bang, might then be viewed as having more the nature of a candle suddenly flaring up from an unknown creation event.

Throughout this discussion of the late universe, I have assumed that life continues to exist. How reasonable an assumption is this? It is conceivable that our species could prolong its existence through various colonization strategies, no matter what happens to the Sun. If we took with us the records of present and future cosmological achievements, then our ancestors could refer to them as evidence for a Big Bang theory. But direct observational confirmation would be extremely difficult and such "archival cosmology" theories could not be proved or disproved. It would have to be taken on faith. In this situation, cosmology might take on the status of a religion — which some would argue has already happened! There is also the possibility that new civilizations might arise on young stars and have to construct their cosmology by themselves for the first time. If our thinking about the difficulties of future cosmological observations is true, these new civilizations will not get very far.

Very Late Times

Of course the universe will not abruptly end when it has expanded a factor of ten or a hundred from its present size. There are essentially two different outcomes possible: if the density of matter in the universe is at or below some critical value, gravity cannot halt the expansion. This means the universe is open and will expand forever. If the density is above the critical

value, the universe is closed and will eventually recollapse. In the latter case, depending on the exact value of the density, recollapse may take place after a relatively short amount of time, say another 20 billion years. Or it may take place after a relatively long period of time, hundreds of billions of years or 10^{100} billions of years. No one knows.

If the universe recollapses after only 20 billion years, the epoch of observational cosmology will extend until that moment when the background radiation has heated up sufficiently to fry all existing cosmologists. If the universe recollapses after hundreds of billions of years, galaxies will recede from view for a long period, during which cosmology will go into hibernation. Eventually galactic remnants will come back into view as the universe recollapses, and cosmology will experience a renaissance. (This assumes that recollapse takes place in less than 100 trillion years — or there won't be any stars left burning.)

The most distant galaxies would naturally exhibit blueshifts (due to the universe's collapse) rather than redshifts. If they were bright enough to observe, these blueshifts might lead any newly emergent civilization to arrive at a Big Crunch model of the universe. But would there be any reason to suspect a previous expansion phase? The nearby galaxies would still show some recession, so the universe would show evidence for both a Big Bang and a Big Crunch. The background radiation would be heating up, not cooling down — no Big Bang clues there — and the isotope abundances would have long since ceased to bear any resemblance to their original values. Thus a civilization existing at that time without archival information might arrive at a skewed picture of the universe. Civilizations with archival information would have the right picture, but the experimental evidence would be mixed.

At the other extreme, the universe could expand forever or recollapse after such a long period of time that it might as well be considered infinite expansion. Such a scenario is an outcome of the popular inflationary universe model. According to inflation, the density is so nearly critical that if the universe does recollapse it will be only after 10^n ages of the universe, where n is a very large number. In this case, the universe model most likely to be developed by a cosmologist would be that of an island-universe.

Is Cosmology a Sometime Thing?

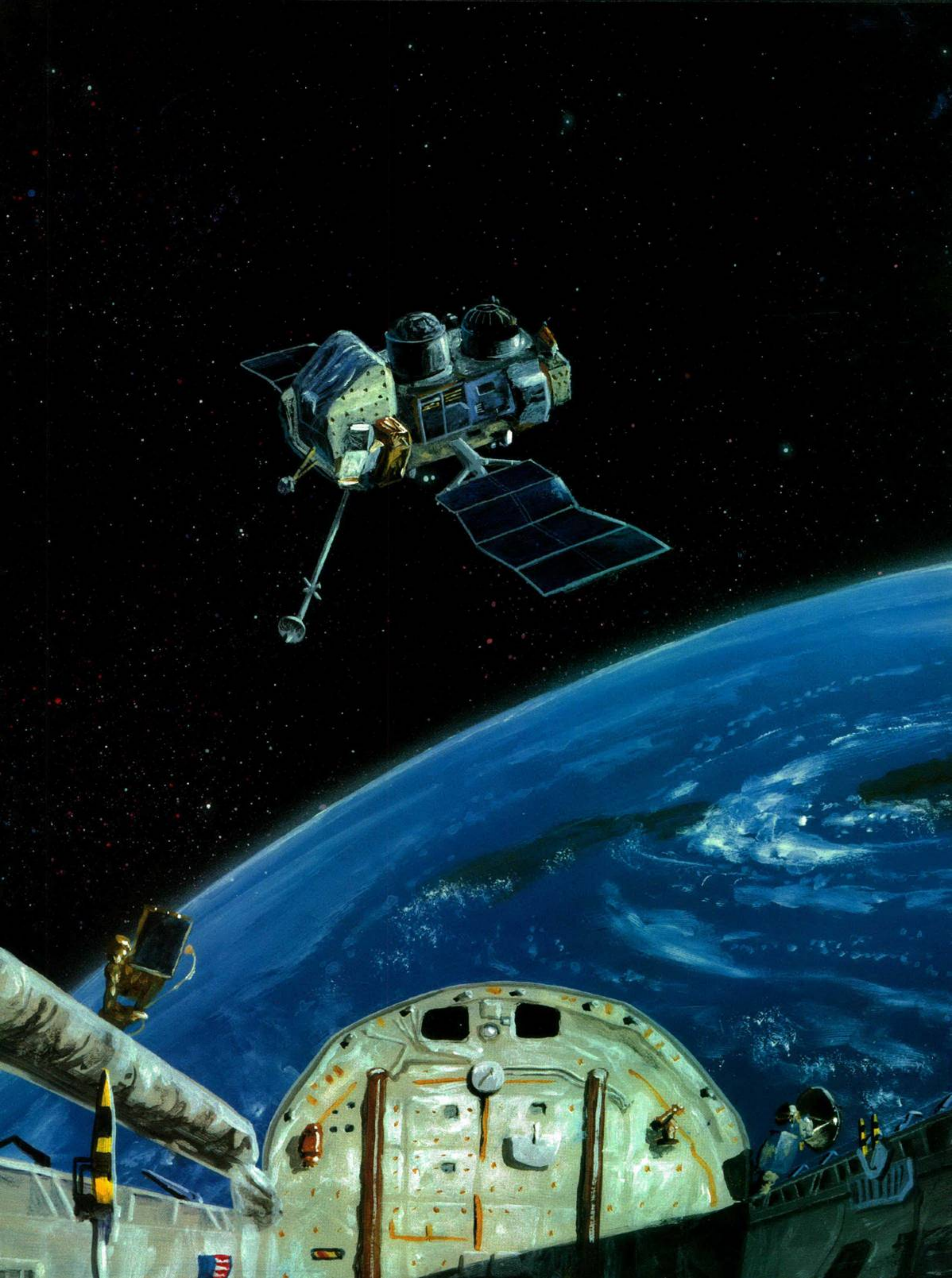
Much of this is highly speculative. If the ruminations have any correspondence to reality, then one would conclude that in our universe, astronomers can make cosmological observations from the time when the universe was about a factor of five smaller than it is now until a time when it is a factor of ten or so larger than it is now. In a closed universe, there will be an additional period of observation during the collapse phase until the background radiation gets hot enough to boil water.

Throughout the argument I have tacitly assumed that the universe is more or less described by the standard model and that we live in the epoch of observational cosmology. In the standard model of the universe all parts of the universe look the same. But suppose on some very large scale (beyond what we can presently observe) the universe is not so uniform and that different regions have different properties. The density may vary from region to region or galaxies may cluster in a different manner, and so on. As the universe expands, these new regions will come into view, and it will become evident that the standard model — which postulates perfect uniformity — was, after all, incorrect. In that case, our descendants would have to conclude that despite what we ourselves think, the present epoch is *not* one in which all the relevant cosmological facts are knowable.

This raises an interesting proposition — to what extent are the questions we raise as cosmologists a function of our historical epoch? The inflationary universe provides a good example of the problem. Inflation was developed in part to explain why the universe is so flat — in other words, why the density is so nearly critical. But this state of affairs may depend on the epoch of observation. If we wait long enough, the equations of relativity will always change a nearly flat universe to one that is curvature dominated, which means that the density will always be pushed away from the critical value. Thus the question inflation attempts to answer — "Why is the universe so flat?" — is only a temporary dilemma and will eventually disappear.

It's a good lesson to bear in mind. If our picture of the universe is strongly influenced by when we happen to observe, then it is conceivable that universes could exist in which life arises only at times when observations lead to a deceptive understanding of cosmology. □

Tony Rothman teaches general relativity at Harvard University. This article is adapted from a chapter in his new book A Physicist on Madison Avenue *(Princeton University Press).*



PROBING THE MYSTERIES of a universe teeming with violent, high-energy events, the Gamma Ray Observatory prepares to observe a distant black hole. Illustration by Michael Carroll.

NASA'S GREAT OBSERVATORIES

An Eye on the Violent Universe

NASA's new Gamma Ray Observatory will revolutionize our understanding of the most cataclysmic events in the cosmos.

by Robert G. Nichols

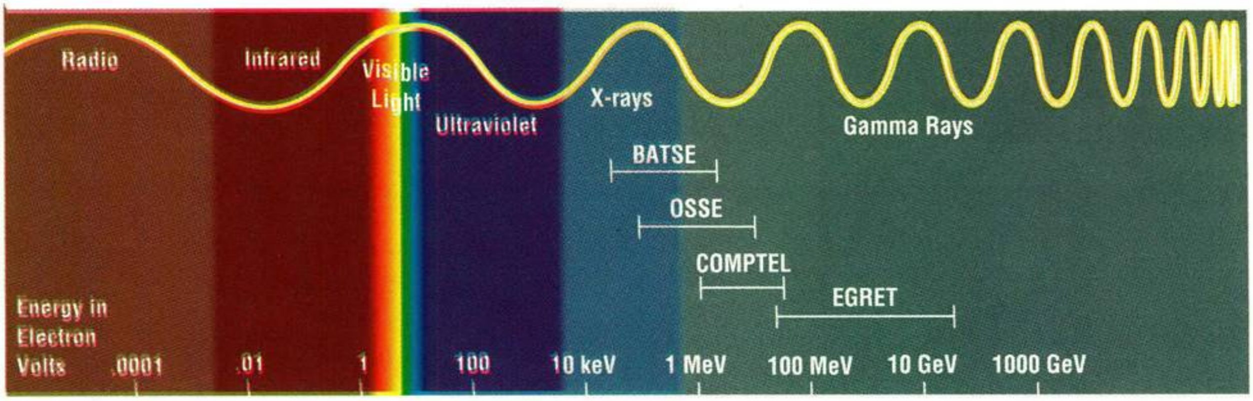
When the space shuttle Atlantis roared from the launch pad on the morning of April 5, the largest scientific payload ever to fly on the shuttle lay nestled in its cargo bay. Two days later the shuttle astronauts deployed the huge spacecraft — the Gamma Ray Observatory — the second jewel in NASA's Great Observatories program. Along with the Hubble Space Telescope and two observatories scheduled to fly later this decade, the Gamma Ray Observatory will help astronomers explore the universe across the entire electromagnetic spectrum.

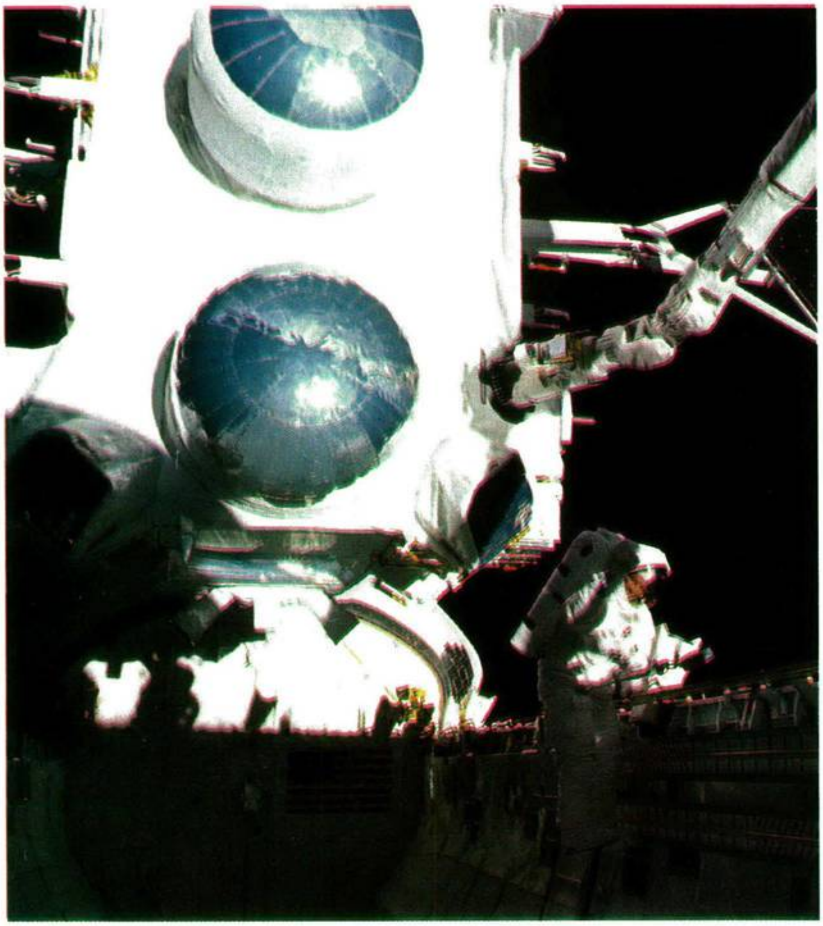
Since deployment, astronomers have been checking out the spacecraft, making sure that the $550 million observatory is operating as it should. Over the next few months the Gamma Ray Observatory (or GRO, as acronym-happy NASA has dubbed it) will begin to observe the universe at gamma-ray energies. Over the next several years, the observatory promises to provide astrophysicists with new insights into the violent forces that shape the universe.

The overarching goal of the GRO program is to expand our understanding of violent, high-energy events in the universe. Gamma rays have the highest energies of any form of electromagnetic radiation, and they spew forth in great quantities only from highly energetic objects. Black holes, supernovae, quasars, pulsars — these are just some of the exotic objects astronomers will scrutinize with the instruments on GRO.

Gamma-ray astronomy offers several important advantages over astronomical studies at other wavelengths. Because gamma rays have extremely high energies, they can travel vast distances through space without being deflected or absorbed. Thus, they can provide information about events and objects from almost any region of the Galaxy and universe. Gamma-ray sensors can give scientists a window on events that occur behind otherwise impenetrable dust clouds on the other side of our Galaxy and in distant galaxies. Because GRO can detect gamma rays from such vast distances, in many cases it will be observing events that occurred when the universe was still young.

Realizing the potential of gamma-ray astronomy, NASA orbited several small gamma-ray observatories in the 1970s. First were the Small Astronomy Satellites 1, 2, and 3, and these were followed by the more advanced High Energy Astronomical Observatories 1 and 3. Though these craft were designed as x-ray observatories, they detected gamma rays in the





X RAYS PALE in comparison to the super-energetic gamma rays, the highest-energy form of electromagnetic radiation (top). The Gamma Ray Observatory (above) will scan the universe at these energies as never before. NASA photo.

lower energy ranges — what are called "soft" gamma rays. The discoveries made by these early observatories hinted at the important science that could be accomplished by instruments sensitive to higher energy gamma rays.

Unfortunately, the very properties that make high-energy gamma rays useful to astronomers also make them difficult to study. Highly energetic gamma rays act more like particles than light waves and pass right through traditional optical instruments. In addition, the universe is not bathed in a sea of gamma rays — there simply are not a lot of them out there to observe. To observe gamma rays then, a sensor must be very dense (to capture a significant fraction of the individual gamma rays that strike it) and very big (to capture large numbers of gamma rays). This is the best way to describe the instruments on GRO. "Our instruments are 1.6 meters on a side and about 2.5 meters tall," explains Donald Kniffen, project scientist for GRO at NASA's Goddard Space Flight Center. Altogether the instruments weigh a total of 5,440 kilograms (12,000 pounds).

The need for large instruments is the main driving force behind the overall design of GRO. In the community of scientific satellites, GRO is a colossus. Measuring 9 meters (30 feet) long and about 4.5 meters (15 feet) in diameter at its widest point, GRO weighs in at 15,875 kilograms (35,000 pounds). That makes it the largest unmanned spacecraft ever launched by NASA. In comparison, the 14.5-meter (48-foot) long Hubble Space Telescope weighs only 9,100 kilograms (20,000 pounds).

GRO was built by TRW Inc. of Redondo Beach, California, a company that has been building spacecraft since the start of the space age. In addition to constructing the spacecraft, TRW was also responsible for integrating the massive instruments into the vehicle.

GRO's massive bulk taxed TRW's spacecraft construction capabilities to the limit, according to Ron Cline, assistant program manager for spacecraft engineering at TRW. The largest previous TRW spacecraft weighed in at 2,267 kilograms (5,000 pounds). The leap to 15,875 kilograms for GRO represented almost an order of magnitude increase to the seasoned spacecraft builder.

GRO is powered by two large solar panels that provide 2,000 watts of electricity. When fully extended, the solar panels stretch 21 meters (70 feet) from tip to tip. During the time when the craft is in Earth's shadow, it runs on power stored in its batteries. GRO also carries 1,900 kilograms (4,200 pounds) of hydrazine fuel, which the on-board thrusters will use to keep the observatory in its proper orbit throughout the life of the mission.

The Tools

At the heart of GRO are its four instruments, which together will "observe the universe across a wide dynamic range, almost six orders of magnitude of energy," Kniffen says, from 30,000 to 30 billion electron volts. This is the first time an observatory will cover the whole gamma-ray region. Earlier gamma-ray spacecraft conducted their observations in much narrower energy ranges.

The instruments carried on-board GRO are 10 to 20 times more sensitive than any previous gamma-ray sensors placed in orbit. This added sensitivity effectively increases the volume of the universe that can be observed in gamma rays by a factor of 300.

Because most gamma-ray sources are fairly weak, GRO's instruments will be pointed at a given area of the sky for a period of two weeks. This gives the sensors time to collect a sufficient number of gamma rays. When the two weeks are up, the spacecraft will point to a different area of sky and begin another period of observation. Over the course of two years, GRO's four instruments will cover the entire celestial sky, completing the first all-sky survey of the gamma-ray universe.

The Burst and Transient Source Experiment (BATSE) on GRO will study mysterious gamma-ray bursts. These bursts are extremely energetic but are difficult to study because they appear at random and are short-lived. Thus, BATSE employs eight identical detectors (four on the top of the spacecraft and four below) that simultaneously observe approximately two-thirds of the sky. "This is a key to finding out where gamma rays are coming from," Kniffen says. "By looking at the bursts we can learn whether or not they are coming equally from all directions or if they come predominantly from the galactic disk." To help analyze these burst sources, BATSE measures time variations to better than a millisecond.

While BATSE studies burst sources of gamma rays, GRO's other three instruments will study steady sources. Looking at the most energetic phenomena (20 MeV to 30,000 MeV) is the Energetic Gamma Ray Experiment Telescope (EGRET). EGRET can determine the location of a gamma-ray source to within about 10 arcminutes (0.17 degree). By observing both point and extended gamma-ray sources, EGRET will provide astronomers with a look at the most energetic and dynamic processes shaping the structure of the universe.

The middle energy ranges (1 MeV to 30 MeV) will be covered by the Imaging Compton Telescope (COMPTEL), which is actually a pair of sensor arrays mounted one above the other. The Oriented Scintillation Spectrometer Experiment (OSSE) focuses its observations on the low end of the gamma-ray spectrum, 100,000 electron volts to 10 MeV. Consisting of two pairs of instruments, OSSE can have one pair monitor background readings while the other observes gamma-ray sources.

The three steady-source instruments employ distinctly different observing technologies best suited for their specific energy ranges. Gamma rays entering EGRET interact with sheets made of tantalum, producing an electron-positron pair. By analyzing the properties of the electron-positron pair, EGRET can measure the energy of the incoming gamma ray, the direction of its source, and the time of its arrival.

The dominant process with COMPTEL is the Compton interaction, in which an incoming gamma ray interacts with a free electron in the upper detector. The electron picks up some of the energy of the gamma ray, which is then deflected. The lower detector then absorbs the gamma ray and measures its somewhat lower energy. Astronomers can reconstruct the direction of the original gamma ray and its energy from observing these interactions.

OSSE uses the photoelectric effect to observe low-energy gamma rays. A gamma ray entering the instrument collides with an electron in orbit around a nucleus. The electron gets a boost in energy and when it drops back to the ground state, it releases a photon of visible light. A photomultiplier tube then detects and measures the photon.

Operating together, these four instruments cover an energy range far wider than that studied by any previous gamma-ray observatory. Observations of gamma rays with energies higher than 30,000 MeV, which can penetrate Earth's atmosphere, will be left to ground-based observatories.

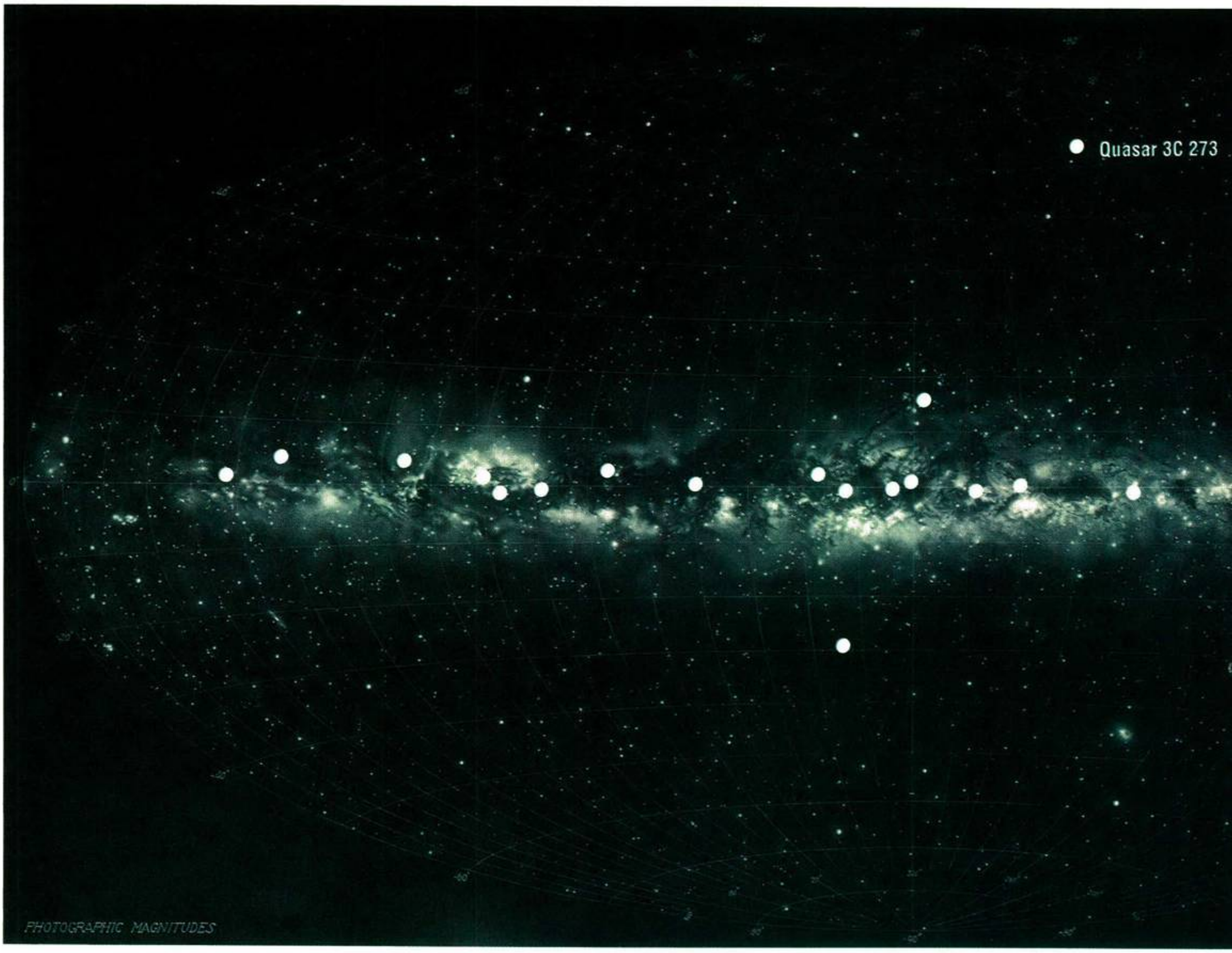
The Science

GRO's forte is probing the highly energetic events that emit large numbers of gamma rays. None is more energetic than a supernova explosion. Six months after supernova 1987A exploded in the Large Magellanic Cloud in February 1987, astronomers first detected gamma-ray emissions from the explosion's debris. "One of the greatest achievements of modern-day astrophysics came from the observation of gamma-ray lines from supernova 1987A," Kniffen claims. He adds that the gamma rays were from the decay of cobalt 56, which eventually decays into iron. The observations support the theory that supernovae are a significant source for the heavy elements in the universe.

Kniffen believes that GRO will garner more information from supernova 1987A, including observations of the decay of cobalt 57. If GRO does observe that isotope, it will provide additional details about the density of neutrons during the first few seconds following the supernova. "The book is not closed on supernova 1987A," Kniffen adds, at least as far as GRO is concerned.

And GRO's observations of supernovae won't be limited to supernova 1987A. The great sensitivity of GRO's instruments will allow astronomers to observe supernovae in even more-distant galaxies. At least one of GRO's instruments will be able to observe out to the Virgo cluster where, Kniffen predicts, a supernova is likely to occur during GRO's 8- to 10-year lifetime.

Pulsars are another class of object scientists are eager to study at gamma-ray energies. Although astrophysicists have long predicted that pulsars would be a source of gamma-ray emissions, to date gamma rays have been observed from only two pulsars. What is interesting about these two pulsars, according to Kniffen, is that "their gamma-ray emissions are very similar. In one rotation of the neutron star we see two pulses separated by 0.4 of the total period of rotation." At radio frequencies, however, these pulsars have very different signatures. As GRO observes gamma-ray emission from other pulsars, it will be interesting to see if the



GAMMA-RAY SOURCES GALORE should result from GRO's all-sky survey, in marked contrast to the few dozen sources now known (circles). GRO's instruments, more sensitive than previous ones, will observe areas that have yet to be explored in detail. Lund Observatory map.

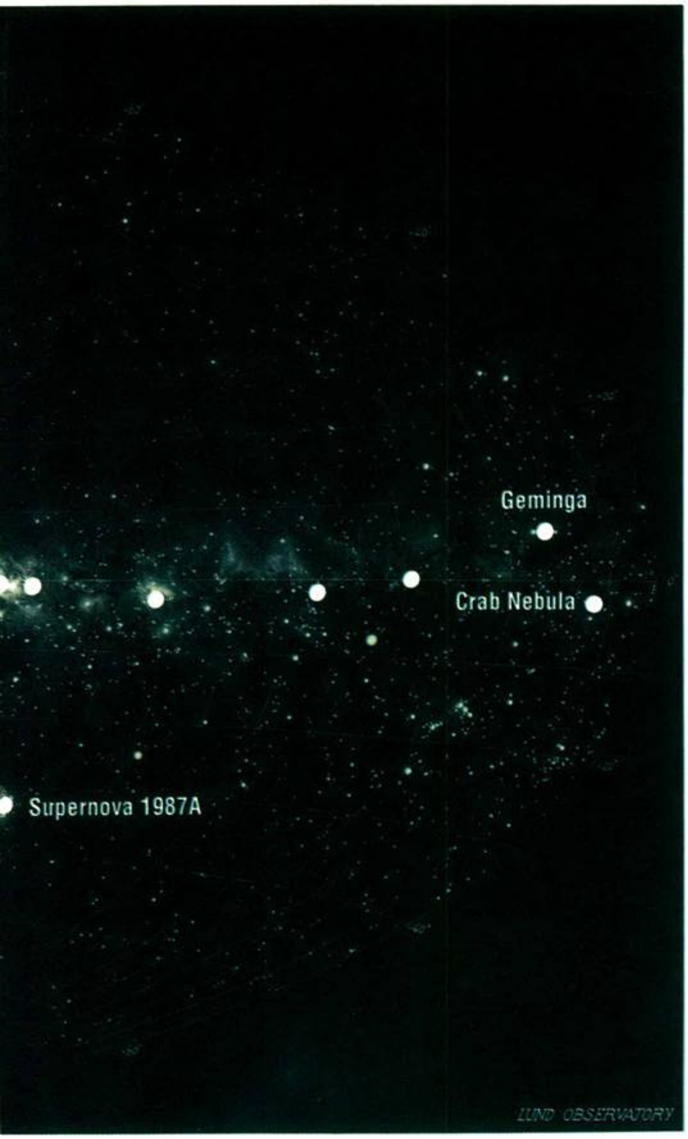
gamma-ray signatures remain the same while the radio signatures continue to vary.

Coordinating GRO's pulsar observations with those of ground-based radio observatories will be vital in trying to understand these unique objects. Radio telescopes can precisely measure a pulsar's rotation rate, something that cannot be done with GRO's instruments. Knowing a pulsar's exact rotation and how it varies, astrophysicists can analyze GRO's data to see if the gamma rays are pulsed during that period. Fortunately, the radio observations don't have to occur simultaneously with GRO's observations, but they must be contemporary. Kniffen says that "radio astronomers all around the world are starting to take these measurements two or three times a year so that they can be sure to bracket GRO's observations."

GRO observations may also help explain why some active galaxies spew out prodigious quantities of gamma rays. Before GRO, gamma-ray instruments had probed two Seyfert galaxies and one radio galaxy. In some cases, the gamma-ray emissions were greater than those in all the other frequencies. Why do these objects emit so many high-energy gamma rays? That's one question astronomers hope GRO will help answer. Perhaps the observations will support the theory that these energetic objects are powered by supermassive black holes.

Closer to home, GRO will try to find the source of the 500,000 electron volt gamma-ray emission that seems to be coming from the general vicinity of the galactic center. "The source seems to vary with time," according to Kniffen, "and there is the belief that this may be the best evidence that there is a black hole at the center of the Galaxy." Kniffen does admit, however, that some observations indicate that the source remains unvarying, which would argue against the black hole theory. Kniffen hopes that the extremely sensitive instruments on GRO will settle the debate.

GRO's instruments will be focused not just on ob-



LUND OBSERVATORY

jects in deep space. As part of a world-wide campaign called Max 91, GRO will turn its attention to something closer to home: the Sun. Gamma-ray observations of the Sun will provide solar astronomers with new information about how particles are accelerated in solar flares. GRO will coordinate these observations with the Very Large Array radio observatory, optical observatories on Earth, and balloon-borne instruments.

In addition to ground-based observatories, GRO scientists will coordinate observations with other orbiting observatories. In fact, GRO is part of a fleet of four advanced observatories that NASA has dubbed the Great Observatories. Each of these observatories will monitor and study the sky in a particular region of the spectrum. The first to be launched was the Hubble Space Telescope, which is designed to observe optical and ultraviolet radiation. Following GRO later this decade will be the Advanced X-ray Astrophysics Facility and the Space Infrared Telescope Facility.

Systematically coordinating observations — for example observing the same quasar in the gamma-ray region with GRO while the Advanced X-ray Astrophysics Facility studies it in the x-ray region — will greatly enhance the information acquired on an object or event. Comparing the information from the two observatories, scientists might modify their observing schedules to monitor new and unexpected events.

The Mission

GRO orbits Earth at an altitude of about 280 miles (450 kilometers). Ron Cline of TRW explains that if the observatory were any higher, it would be in the Van Allen radiation belts, which would raise havoc with the instruments. If GRO were much lower, however, it would encounter significant atmospheric drag and have to burn up too much of its on-board rocket propellant to remain in orbit. By remaining at its current altitude, GRO can use its rocket propellant sparingly and extend the life of the mission from the originally planned 2 years to 8 to 10 years, Cline says.

At the end of its life, there are two things NASA can do with GRO. One option is to retrieve it with the space shuttle. This wouldn't be done so the craft could be refurbished and flown again. In fact, it's unlikely that the instruments would be very useful after being in space for 10 years. Instead, NASA would retrieve GRO to keep the massive spacecraft from crashing back to Earth. If GRO does re-enter the atmosphere, many large pieces of equipment will survive the plunge to Earth's surface.

Of course, there is always the chance that a shuttle won't be available to retrieve the observatory. Perhaps the shuttle manifest will be too filled with other, more critical missions, so there wouldn't be any shuttles to spare. That's what happened with the Solar Maximum Mission satellite, which burned up in the atmosphere because NASA was unable to mount a retrieval mission. If this happens, GRO will use its onboard rocket thrusters to do a controlled re-entry over the South Pacific. In that case, large pieces of debris would still reach Earth, but they would fall harmlessly into the ocean.

Will NASA follow up on the GRO program? Kniffen doesn't think so, at least not in the sense of another "broad-spectrum, general-survey spacecraft" like GRO. Not only are observatories like GRO expensive, but by carrying so many instruments and trying to conduct a broad range of studies, astronomers are literally putting all their eggs in one basket. A catastrophic failure or accident — such as a piece of space debris smashing into GRO — could end all hope of space-based gamma-ray observations for years.

Future gamma-ray observatories are more likely to be smaller, lower-cost spacecraft carrying a single instrument and designed for specific types of observations. Advances in microelectronics and small rocket booster design make it possible and economical to build and launch several small observatories in the place of a single large, all-purpose spacecraft. In a real sense, these small observatories won't be replacing GRO; they will be building on and refining the observations made by their trailblazing predecessor. □

Robert G. Nichols is a freelance science writer living in Brockton, Massachusetts. His last article was "Voyages to the Worlds of Ice," which appeared in the December 1990 issue.

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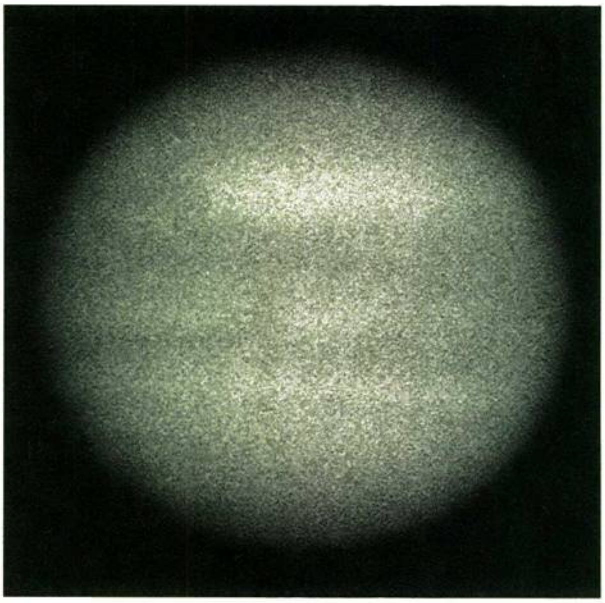
Could be Jupiter.



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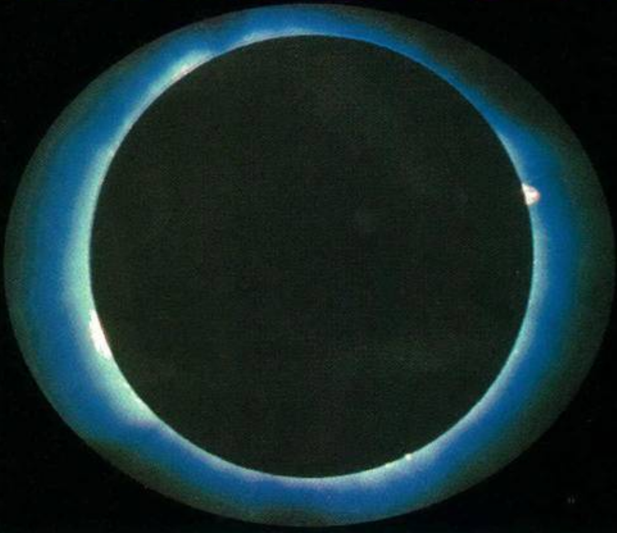

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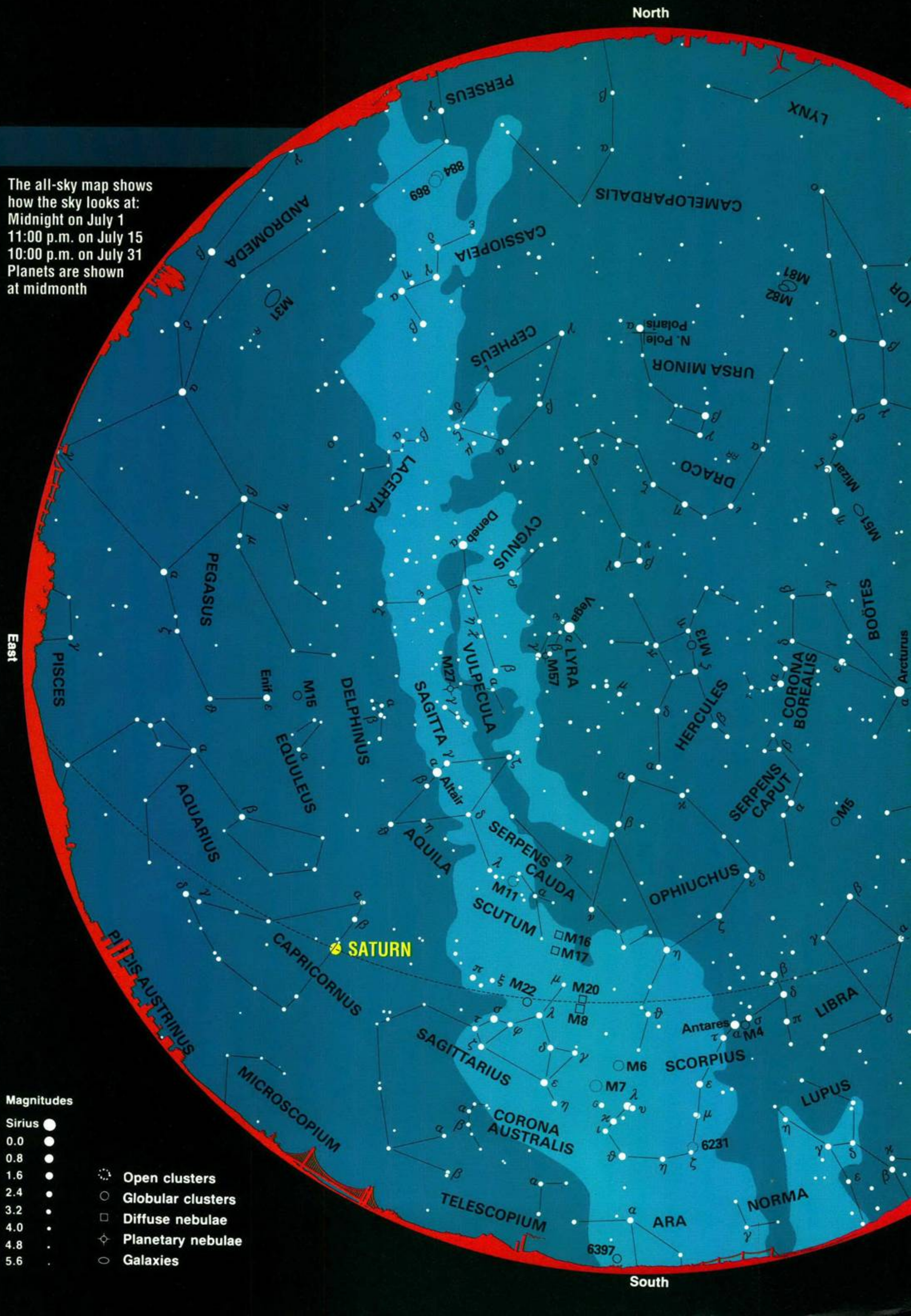
The all-sky map shows how the sky looks at:
Midnight on July 1
11:00 p.m. on July 15
10:00 p.m. on July 31
Planets are shown at midmonth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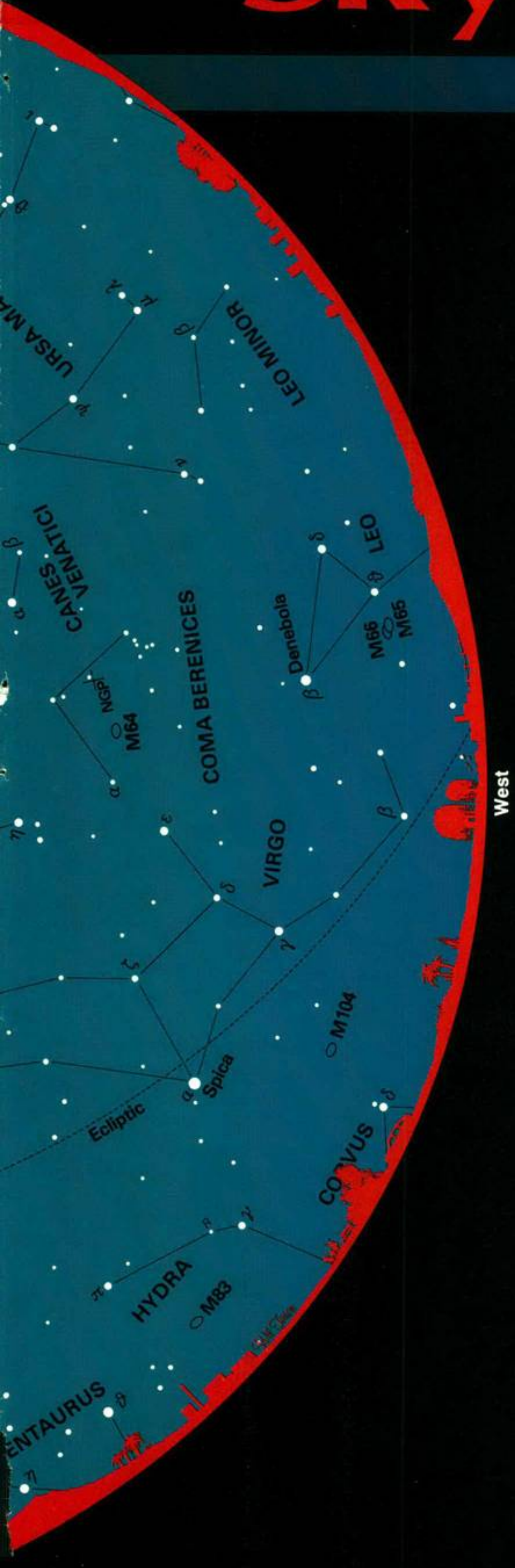
SAGITTARIUS
M6
SCORPIUS
M7
MICROSCOPIUM
LUPUS
CORONA AUSTRALIS
6231
TELESCOPIUM
NORMA
ARA
6397
South
Magnitudes
Sirius
0.0
0.8
1.6
2.4
3.2
4.0
4.8
5.6
Open clusters
Globular clusters
Diffuse nebulae
Planetary nebulae
Galaxies

Sky Almanac

July 1991



SOLAR ECLIPSE ON JULY 11

Observers in parts of Hawaii, Mexico, and Central and South America have a chance to view the astronomical event of 1991 this month — a long and spectacular total eclipse of the Sun. The July 11 eclipse features nearly seven minutes of totality at its peak in Baja California and along the west coast of Mexico, making this the longest total eclipse since 1973. Meanwhile, viewers in most of the rest of North, Central, and South America will be treated to a partial solar eclipse.

SATURN AT ITS BEST

Be sure to look for Saturn on these warm summer nights. The ringed planet reaches opposition on July 26/27 and on that night rises at sunset, is highest in the south around midnight, and sets at sunrise. Saturn is also at its brightest for the year at opposition, shining at magnitude 0.1.

Calendar of Events

4 Uranus is at opposition
Last Quarter Moon is at 10:50 p.m. EDT

6 Earth is at aphelion (94.5 million miles from the Sun)

7 Neptune is at opposition

9 Vesta is in conjunction with the Sun

11 Venus passes 1.0° south of Regulus, 4 a.m. EDT
The Moon is at perigee (222,202 miles from Earth), 6:05 a.m. EDT
New Moon is at 3:06 p.m. EDT; total solar eclipse

13 The Moon passes 3° south of Mercury, 10 a.m. EDT
The Moon passes 3° south of Jupiter, 1 p.m. EDT

14 The Moon passes 5° south of Mars, 11 a.m. EDT
Mars passes 0.7° north of Regulus, noon EDT
The Moon passes 3° south of Venus, 2 p.m. EDT

15 Mercury passes 0.08° south of Jupiter, 4 a.m. EDT

16 Juno is at opposition

17 Venus is at greatest brilliancy (–4.5 magnitude)

18 First Quarter Moon is at 11:11 a.m. EDT

21 Comet Machholz is at perihelion

22 Venus passes 4° south of Mars, 2 a.m. EDT

24 The Moon is at apogee (252,255 miles from Earth), 7:11 a.m. EDT
Mercury is at greatest eastern elongation (27°)

26 Full Moon is at 2:24 p.m. EDT; penumbral lunar eclipse
The Moon passes 1.9° north of Saturn, 4 p.m. EDT
Saturn is at opposition
Mercury passes 2° south of Regulus, 9 p.m. EDT

30 Venus is stationary

Eye on the Sky *by* Deborah Byrd

A GREAT SHOW awaits people across most of North and Central America on July 11 as the Sun goes into eclipse. Whether you'll be in the narrow path of totality or in the broad area of partial eclipse, don't miss this sensational event! Photo by Richard Talcott; map courtesy Fred Espenak, NASA/Goddard Space Flight Center.

THE ECLIPSE OF THE DECADE

A few lucky people will be traveling by air, land, or sea to see the July 11 total solar eclipse. To see the total eclipse, you have to be in the narrow path of totality that runs from Hawaii through parts of Mexico and Central and South America. Meanwhile, most of North America can witness the eclipse's partial phases.

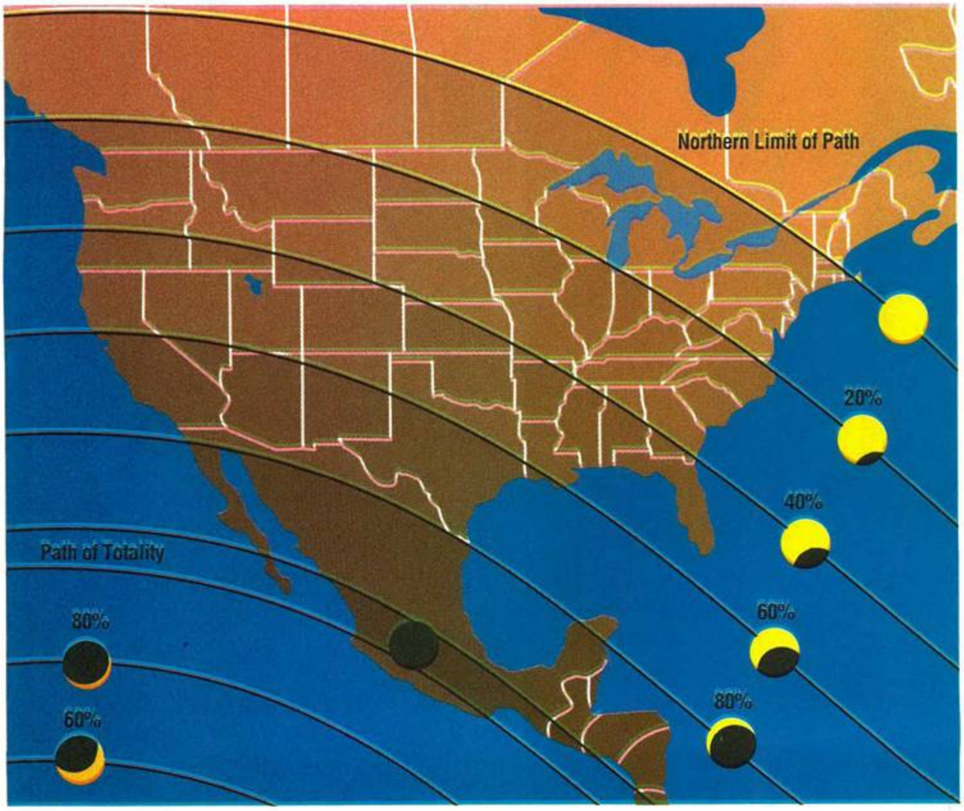
A total eclipse of the Sun is probably nature's most awe-inspiring spectacle. It happens when the Moon passes directly in front of the Sun and the Moon's shadow is cast on Earth. Only those in the dark central part of the shadow experience the precious moments of totality, when the Sun is entirely hidden behind the Moon and an eerie darkness falls on the land.

Although a partial eclipse doesn't have the same emotional appeal as a total eclipse, it is still fun to watch if you're properly prepared. You must remember, however, that the Sun is literally blinding even when partly covered by the Moon. DO NOT GAZE AT THE SUN at any time during the partial eclipse. To do so risks permanent eye damage.

One way you can safely view the eclipse is with a homemade pinhole camera. Simply punch a pinhole in some cardboard and let sunlight pass through it onto a sheet of white paper. This is a great way to show the eclipse to a small group of people. Pinhole cameras also occur naturally. During the annular solar eclipse of 1984, I was treated to dozens of dancing images of the eclipsed Sun that had been projected through the leaves of a tree. (For a complete guide to viewing the eclipse, see "When Worlds Align" on page 62.)

FAREWELL TO THE EVENING PLANETS

This is your last month to get a good view of the planets that have dominated the evening sky throughout the spring and early summer. When July begins, you can easily see three planets in the western twilight glow. Jupiter is closest to the horizon, with Venus and Mars side-by-side and slightly higher in the sky.



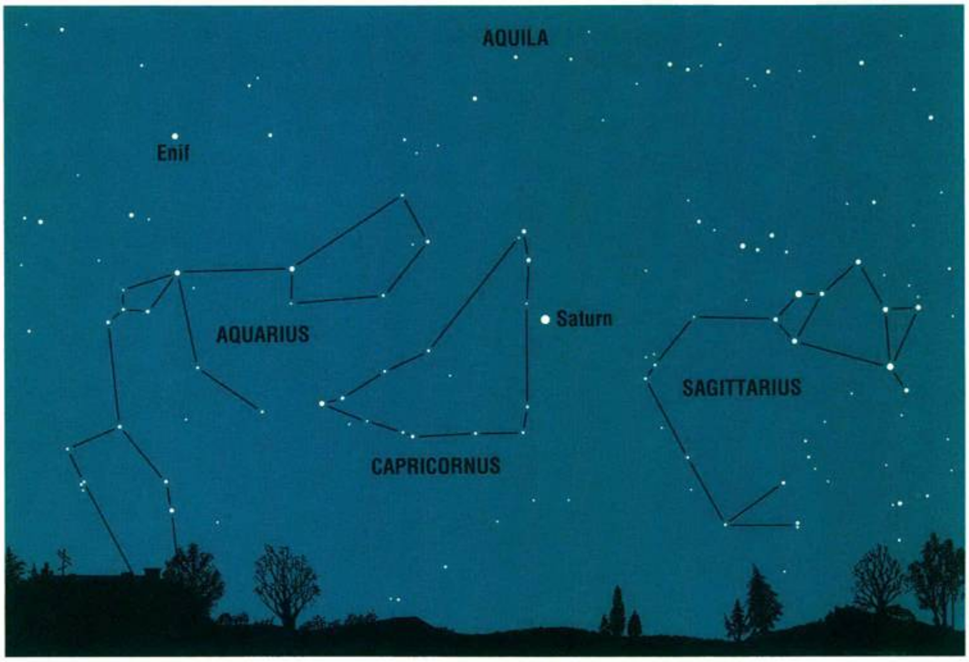
There's actually a fourth planet here, Mercury, but it is harder to see. You can find it with the help of Jupiter, which passes a mere 0.08° from Mercury on the evening of July 14. Aim your binoculars at Jupiter that evening and you'll easily see Mercury. By coincidence, the Moon is also nearby. On July 13, look for Jupiter and Mercury about 7° to the right of the crescent Moon.

On the following evening, the Moon is near a tight trio formed by Venus, Mars, and Regulus, the brightest star in the constellation Leo. This star and these two planets undergo a series of conjunctions this month, as described in the July's Planets section on the following page. By the end of July, Mars is the highest of the three planets in the twilight sky.

SATURN AT OPPOSITION

The golden planet Saturn appears at its brightest for 1991 during July. The 0.1-magnitude planet is at opposition — opposite the Sun in our sky — on the night of July 26/27. On that night, it rises when the Sun sets and sets when the Sun rises. Opposition occurs when Earth, in its smaller and faster orbit, passes between Saturn and the Sun.

Saturn's opposition seems almost anticlimactic in this month of spectacular sky events. But it offers a rare treat for skywatchers. As you watch Saturn rise in the east-southeast on the 26th, quickly turn your gaze westward. If your sky is very clear and you have an unobstructed horizon, you should be able to see all five of the bright naked-eye planets at once in the twilight sky.



SATURN SHINES BRIGHTLY in the southeast on July evenings among the relatively dim stars of Capricornus. Although the ringed planet reaches opposition on July 26/27, it is easier to see around the 20th when the Moon is not nearby.

JULY'S PLANETS

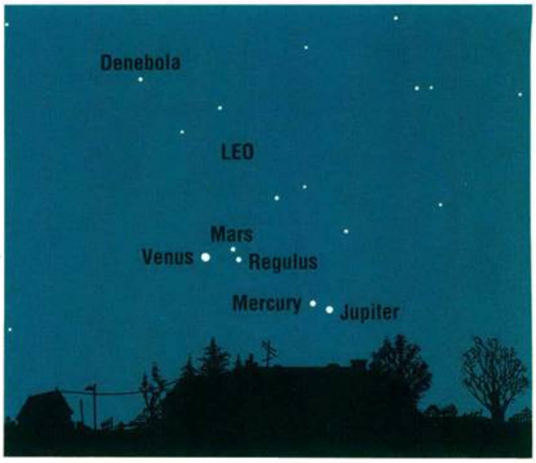
Mercury lies low in the west-northwest after sunset as July begins. It climbs somewhat higher by the time it passes Jupiter on the evening of July 14, when it shines at magnitude 0.1. And Mercury is highest in the sky around the time of its greatest elongation on July 24/25, when it lies 27° east of the setting Sun. Two nights later, it passes 2° south of Regulus. This is a fair-to-middling apparition for Mercury as seen from the Northern Hemisphere and you should be able to spot the planet if you look carefully.

Jupiter appears exceedingly near Mercury on July 14, when both planets are low in the sky. Jupiter is much easier to see because it is so much brighter, shining at magnitude –1.8. Unfortunately, Jupiter is rapidly approaching the twilight glare and will disappear from view by the beginning of August.

A bit higher in the twilight glare is the brightest planet of all, Venus. On the night of July 16/17 it reaches greatest brilliancy, when it shines at magnitude –4.5. Venus passes 1.0° south of Regulus on July 10/11 and 4° south of Mars on July 21/22. Like Jupiter, Venus is sinking rapidly toward the sunset glare. It will pass between the Sun and Earth next month.

Mars remains in the company of the other evening planets, but it is much dimmer at magnitude 1.8. It passes 0.7° north of the slightly brighter star Regulus on the evening of July 14. After sweeping near Venus on July 21/22, it ends the month as the highest of the planets in the western twilight sky. It will remain in the evening sky until September, long after the other planets have disappeared.

FOUR PLANETS AND A BRIGHT STAR gather low in the west during evening twilight around mid-July. On the evening of July 16, Venus is at its brightest and is by far the easiest to see, but you should be able to spot Mercury, Jupiter, Mars, and Regulus if you look carefully.



THE STARRY SKY

July is an excellent time to come to know the constellation Draco the Dragon. Draco is one of several northern constellations that are "circumpolar," which means that they never sink below the horizon as they circle endlessly around Polaris, the Pole Star. Draco, Ursa Major, Ursa Minor, Cepheus, Cassiopeia, and Camelopardalis are all circumpolar as seen from latitudes of 40° north or higher.

From more southerly latitudes, these constellations (or parts of them) do occasionally dip below the northern horizon. That's why July is a good month for Draco. It's now riding at its highest in the north each evening.

I always notice Draco while gazing toward the bright star Vega in the constellation Lyra, which is now high in the east each evening. A pair of stars near Vega draws my eye. Although these stars aren't brilliant, they're noticeable because they are separated by only 4°. These stars are Eltanin and Rastaban, in the head of Draco.

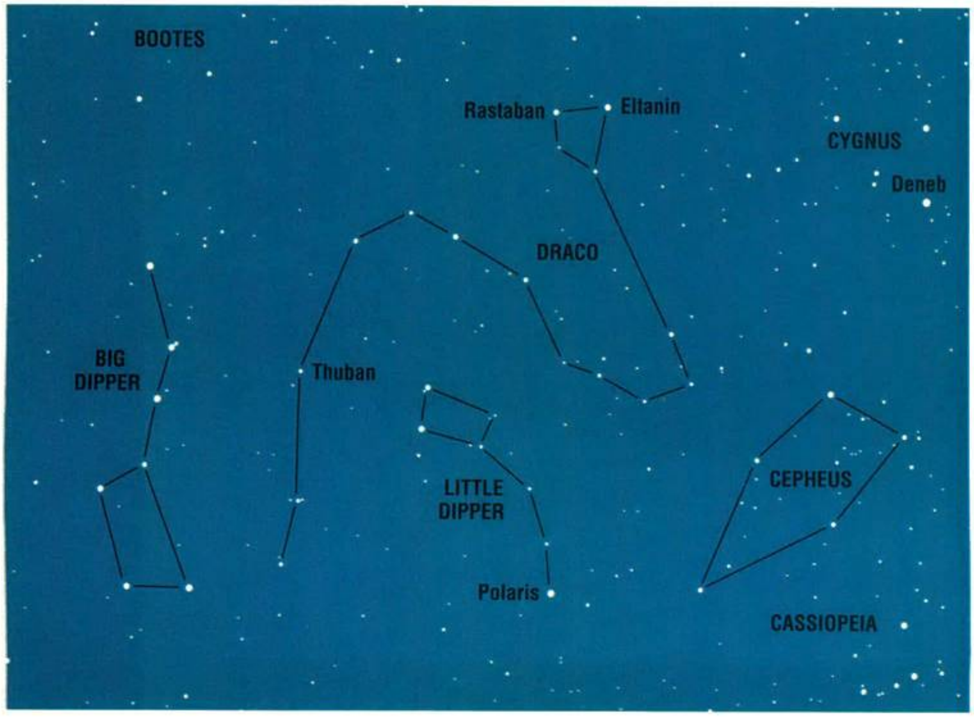
Eltanin's name sounds magical to me, as if it were invented by elves. In truth, it's derived from an Arabic phrase meaning "the dragon's head." Eltanin is a 2nd-magnitude star located about 100 light-years away. Rastaban shines more dimly, at 3rd magnitude, and with good reason: it is nearly three times farther away. Eltanin and Rastaban join with two fainter stars to form the Dragon's head.

If you use your imagination, Draco makes a fairly convincing dragon. From the head, Draco's stars track to the northeast toward the constellation Cepheus. Then they suddenly bend back to arc around the bowl of the Little Dipper, one of the sky's most famous asterisms, in the constellation Ursa Minor. Finally, Draco's stars snake between the Big and Little Dippers. In all, the Dragon's stars circle nearly halfway around the sky's pole. You might fancy Polaris as a celestial jewel guarded by Draco.

Dragons play prominent roles in the lore of many cultures. Draco is often associated with a Babylonian dragon god called Tiamat, who was conquered by the Sun god, represented in the heavens by our constellation Hercules.

In Greek mythology, Draco is sometimes identified as the dragon slain by Cadmus, who founded the city-state of Thebes. Athena told Cadmus to sow the ground with the dragon's teeth. He did, and an army rose up from the teeth to fight alongside Cadmus. In another Greek legend, Draco guarded a tree bearing golden apples. Draco is connected to Hercules in this incarnation as well, for Hercules was called upon to slay the dragon.

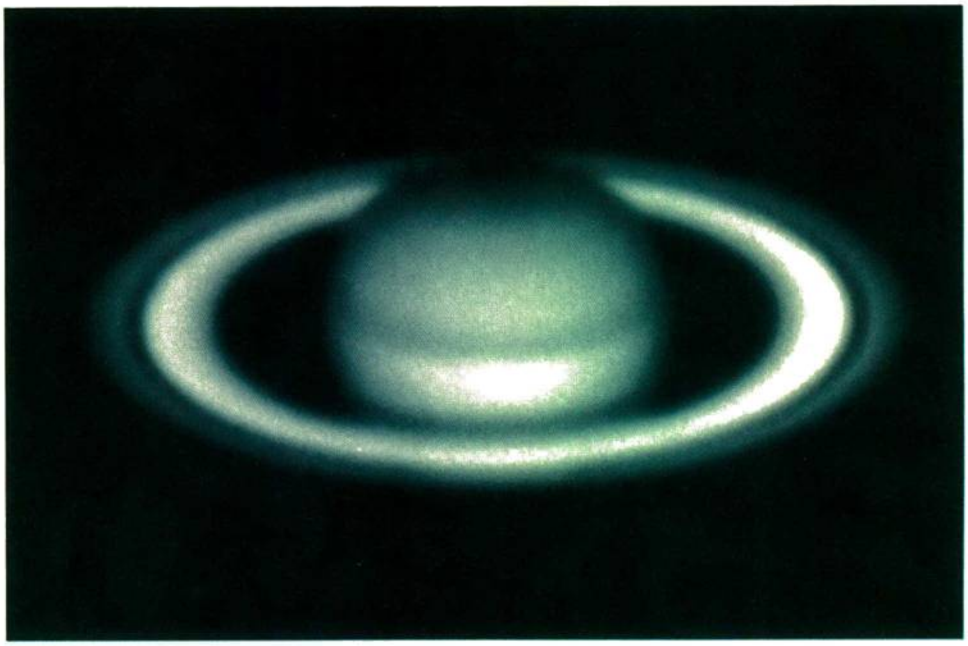
DRACO THE DRAGON lies high in the northern sky late on July evenings. Draco's distinctive head features the conspicuous stars Eltanin and Rastaban, while the rest of its body curves gracefully between the Big and Little Dippers.



Any introduction to Draco is incomplete without mention of an inconspicuous star called Thuban, which lies nearly on a line between Polaris and the end of the Big Dipper's handle. Fourth-magnitude Thuban was the pole star some 5,000 years ago. The early Egyptians apparently used sightings of this star to orient the pyramids. The location of the celestial pole has now shifted due to precession, a 26-thousand-year "wobble" in Earth's axis of rotation. But this same motion will cause the pole to return to Thuban again, in another 20,000 years. □

Deborah Byrd is the creator, writer, and producer of "Star Date," an independently syndicated daily radio series on commercial and public radio.

A SPECTACULAR ECLIPSE



SATURN APPEARS BIGGER and brighter this month than at any other time this year. Try to spot the planet's dusky equatorial band and the narrow gap in the ring system known as Cassini's division. Photo by Jean Bourgeois.

The total solar eclipse on July 11 has a lot of folks worked up. It is clearly one of the more exciting astronomical events this decade. Tens of thousands will flock, fly, cruise, and thumb their way to the centerline to witness totality alongside the millions who live there; millions more on either side of the path will settle for a partial eclipse, far from the maddening crowds.

In the midst of this eclipse frenzy, let's not forget common sense. Whether you use a telescope or binoculars, always observe the partial phases either through an over-the-aperture solar filter or by projecting the Sun's image onto a shaded screen. Be cautious when projecting: sustained solar heat can damage optics. Position the Sun in the field of view by making the shadow cast on the ground by the telescope as small as possible. And keep your finderscope capped. Periodically shield your telescope so that it and the optics can cool down. Also stay clear of the projected solar beam, especially if you have long hair or a beard!

Totality lasts over four minutes in Hawaii and nearly seven minutes in Baja and along the west coast of Mexico. This is more than enough time to study the Sun's outer atmosphere in a telescope or get some great photographs. Just prior to totality, watch for "Baily's beads" and the "diamond ring" as the last vestiges of sunlight shoot through the valleys on the lunar limb. When totality commences, remove your filter and view the solar prominences flicking from the solar limb. These tongues of hot plasma extend tens of thousands of miles from the Sun's surface. Also be sure to observe the loops and swirls in the Sun's pearly white corona. They are usually the most fascinating features visible in a telescope during totality. Finally, don't forget to replace your filters *before* totality ends! (For more details on viewing the eclipse, see "When Worlds Align" on page 62.)

Those people wishing to observe the partial phases in a telescope should use a low-power eyepiece with generous eye relief and, of course, either proper filtration or the projection method. In the United States and other locales north of the central path, the Moon will appear to move right to left across the southern part of the Sun's disk. Thus, in a telescope with an inverted field of view, the Moon will encroach on the Sun from the left side. Viewers posted throughout the southwestern United States will see between 60 and 80 percent of the Sun obscured by the Moon. The greatest fraction of the Sun covered by the Moon in the continental U. S., just over 80 percent, can be seen from Brownsville at the extreme southern tip of Texas.

This should be a truly memorable eclipse for all skywatchers. In fact, if astronomical events were like baseball cards, I'd trade three Kohouteks and two Halleys for it any day.

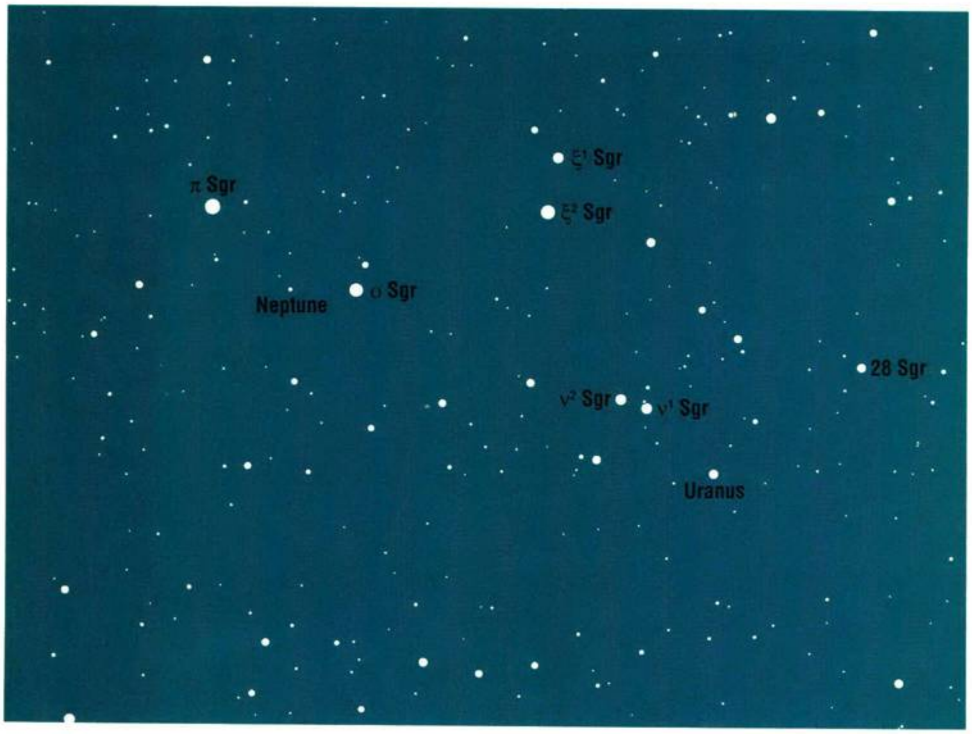
PRIME TIME FOR SATURN

Saturn's 1991 apparition peaks on the night of July 26/27 as the great ringed planet reaches opposition. Rising at sunset and crossing

TIMES AND DURATIONS OF TOTAL ECLIPSE

City	Universal Time	Duration of Totality
Kailua Kona, Hawaii	17h30m	4m09s
Mauna Kea, Hawaii	17h30m	4m12s
Hilo, Hawaii	17h31m	4m07s
La Paz, Mexico	18h51m	6m27s
San Lucas, Mexico	18h53m	5m37s
Mazatlán, Mexico	19h02m	5m42s
Tuxpan, Mexico	19h06m	6m56s
Guadalajara, Mexico	19h12m	6m18s
León, Mexico	19h16m	5m56s
Mexico City	19h24m	6m42s
Cuernavaca, Mexico	19h25m	6m40s
Puebla, Mexico	19h27m	6m27s
Guatemala City	19h50m	5m23s
San Salvador, El Salvador	19h54m	5m21s
Managua, Nicaragua	20h01m	3m12s
San José, Costa Rica	20h08m	5m12s
Cali, Colombia	20h26m	4m40s
Tefe, Brazil	20h41m	3m58s
Manicore, Brazil	20h44m	3m56s

Times are given in universal time on July 11 for the moment of maximum eclipse. Durations are given in minutes and seconds.



URANUS AND NEPTUNE reach opposition within four days and 4° of each other in early July. Look for 5.6-magnitude Uranus about 1° southwest of ν^1 Sagittarii and 7.9-magnitude Neptune about 0.5° east of o Sagittarii.

the meridian around midnight, Saturn has most of the southern sky east of Sagittarius to itself. The brightest stars in its vicinity are 3rd-magnitude Alpha and Beta Capricorni to the north, but they pale in comparison to Saturn's 0.1 magnitude.

At opposition, Saturn lies about 830 million miles from Earth. At this time, its disk reaches a maximum apparent diameter of 18.5" and its north pole is inclined toward us. The rings measure 42" across, which is slightly less than Jupiter's maximum equatorial diameter.

Perhaps no other celestial object conveys the excitement of visual astronomy more than Saturn. Even a department-store refractor at 40x easily shows the planet's pale-yellow ball suspended within a glorious ring system. Because they can be seen *encircling* the planet, the rings endow Saturn with a three-dimensional appearance that both veteran and novice observers find endlessly intriguing.

With a good 4-inch refractor or 8-inch SCT, you can see a dusky equatorial band and dark polar region on Saturn's globe, as well as the hairline gap in the rings called Cassini's division.

IN THE THICK OF THE MILKY WAY

A bit west of Saturn, Uranus and Neptune continue plodding their way through the Milky Way in Sagittarius. On July 3/4, Uranus reaches opposition. At that time it lies nearly 2 billion miles from Earth and has an apparent diameter of 3.8", less than one-tenth the ring span of Saturn.

Neptune, on the other hand, reaches opposition on July 7/8. Because Neptune's orbit is nearly circular, its distance varies by only about 700,000 miles from one opposition to the next. This year, the closest it gets to Earth is about 2.7 billion miles and its disk measures 2.3" across.

Before you can observe Uranus and Neptune, however, you have to find them. At magnitude 5.6, Uranus is barely visible to the naked eye from a dark-sky site, but good luck trying to separate it out of the busy star fields in Sagittarius! To locate Uranus, your best bet is to scan the region about 1° southwest of Nu¹ (ν^1) Sagittarii using binoculars or a wide-field eyepiece on your telescope. (See the finder chart above.) Compared with the stars, Uranus has a distinctive green color, and this is what you should look for. Zoom in with high power once you've pinpointed the planet. You should see a greenish disk. Don't expect to see any detail, however, even at high magnification.

Neptune, being farther away and fainter (magnitude 7.9) than Uranus, is more challenging to find. Again, use the finder chart above and start out with a low-power eyepiece. Look for a dot of color among the stars, in this case, blue-green. The general area is about 4° east-northeast of Uranus' position, or 0.5° east of 4th-magnitude Omicron (o) Sagittarii. Once you have the field identified, use high power (200x or higher) to make out the planet's disk.

TELESCOPIC PLANETS

Venus is still the most conspicuous object in the western evening sky, where it has been since last December after rounding the backside of the Sun. But now its orbit is swiftly carrying it in front of the Sun and the planet's prominence won't last much longer.

On the night of July 16/17, Venus exhibits "greatest brilliancy" as it peaks at magnitude –4.5. The planet's waning crescent phase can be seen easily in a 2- or 3-inch telescope using moderate to high magnification. Try observing Venus just before or after sunset, when the sky is still bright and the planet's bright disk doesn't contrast as strongly as it does with a dark sky.

If you have a clear horizon, you should be able to monitor Venus throughout the course of the month. On July 1, Venus sports a 29.3"-diameter disk that is 39-percent illuminated. At greatest brilliancy, the planet appears larger (37.3" across) and has a noticeably smaller phase (27-percent lit). By July 31, Venus has grown to 46.5" in apparent diameter while its phase has dwindled to 14-percent lit.

ASTEROIDS IN THE EYEPIECE

Since March, a lone "star" has been moving stealthily against the background stars in Aquila. This is the asteroid Juno, the third minor planet to be discovered (in 1804). With a diameter of 150 miles, Juno is the smallest of the first four minor planets to be catalogued. Although this isn't Juno's most favorable apparition ever, you can spot the 9th-magnitude object quite easily in a 4-inch or larger telescope.

If you plot Juno's position from night to night, the asteroid appears to be moving east to west, rather than west to east as it normally does. This effect, known as retrograde motion, is seen every time Earth overtakes an outer solar system body in its orbit. The same thing is happening right now with Saturn, Uranus, and Neptune. Much like a fast car passing a slower moving car on the highway, Juno (the slow car) temporarily appears to move backward with respect to the stars as we (in the fast car) barrel by. As we draw away after opposition, the asteroid will appear to slow down, stop, and then return to its "direct" west-to-east motion.

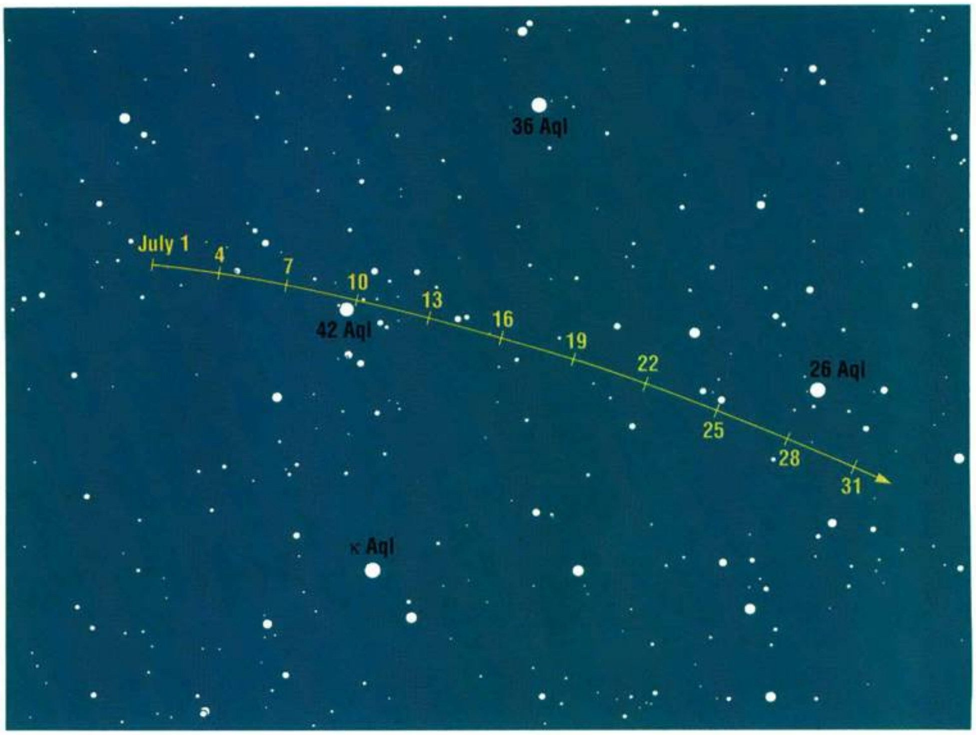
Juno lies in a region about 8° south of Delta Aquilae on the edge of the Milky Way. There it competes in your eyepiece with many stars of similar magnitude. Consult the chart at right to help you locate the area in your finderscope. Next, use a moderate-power eyepiece to identify the field and locate your reference stars. Once you're in the right spot make a sketch of the star field, then come back to it an hour or so later. The "star" that moved slightly is Juno. □

A former associate editor of ASTRONOMY, Jeff Kanipe is now the editor of Star Date *magazine, which is published by the University of Texas' McDonald Observatory in Austin, Texas.*

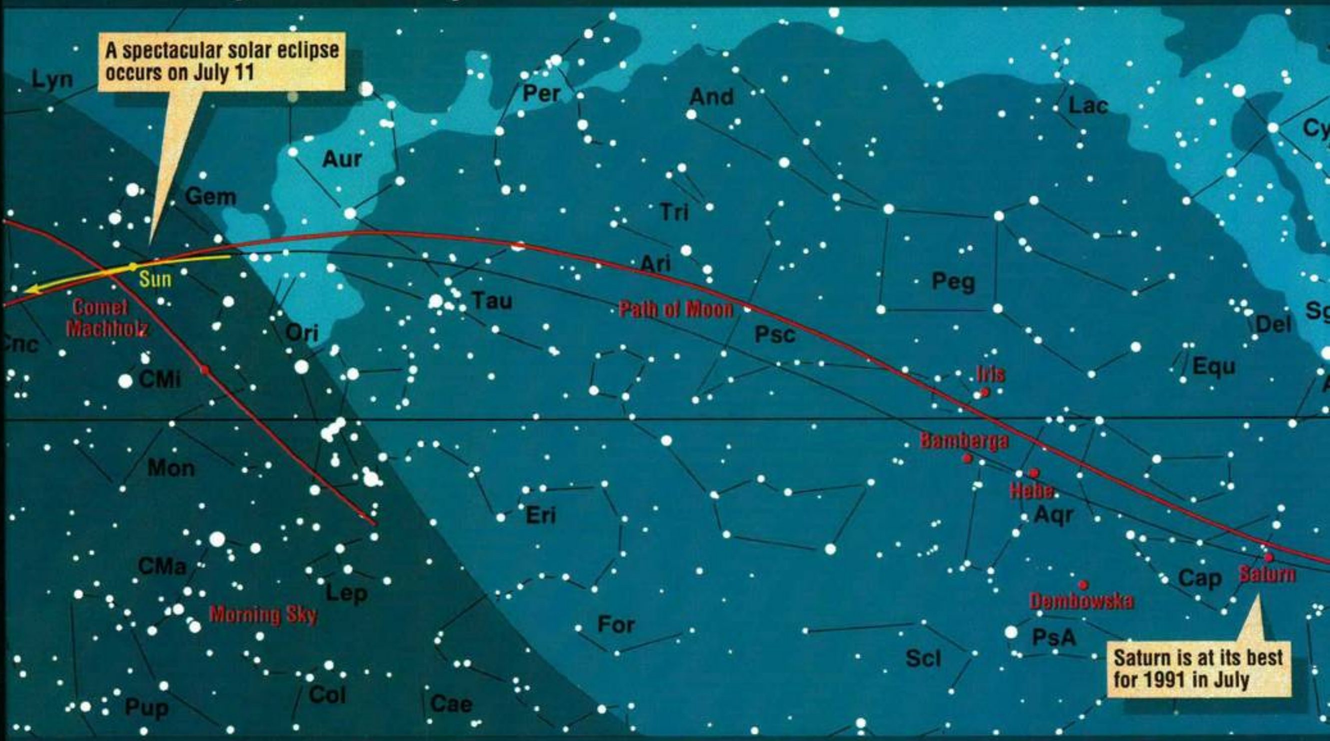
COORDINATES FOR JUNO

Date	R.A. (2000)	Dec.
July 1	19h44.8m	–4°14'
July 4	19h42.5m	–4°20'
July 7	19h40.0m	–4°26'
July 10	19h37.4m	–4°35'
July 13	19h34.8m	–4°44'
July 16	19h32.1m	–4°55'
July 19	19h29.4m	–5°08'
July 22	19h26.8m	–5°21'
July 25	19h24.2m	–5°36'
July 28	19h21.7m	–5°52'
July 31	19h19.2m	–6°08'

ASTEROID 3 JUNO comes to opposition in mid-July among the stars of southern Aquila. Juno's positions are shown for 11 p.m. EDT (10 p.m. CDT, 9 p.m. MDT, and 8 p.m. PDT).



The Solar System July 1991


A spectacular solar eclipse occurs on July 11
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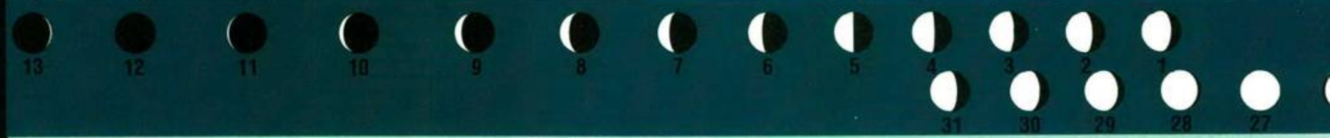
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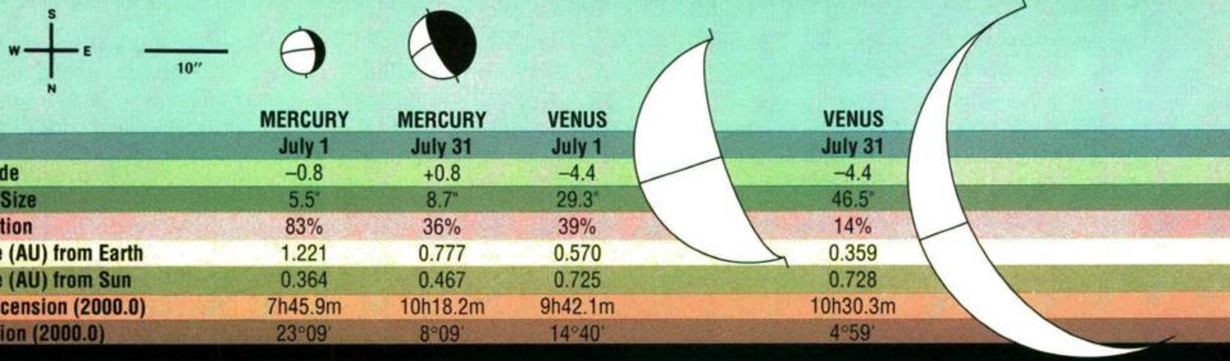
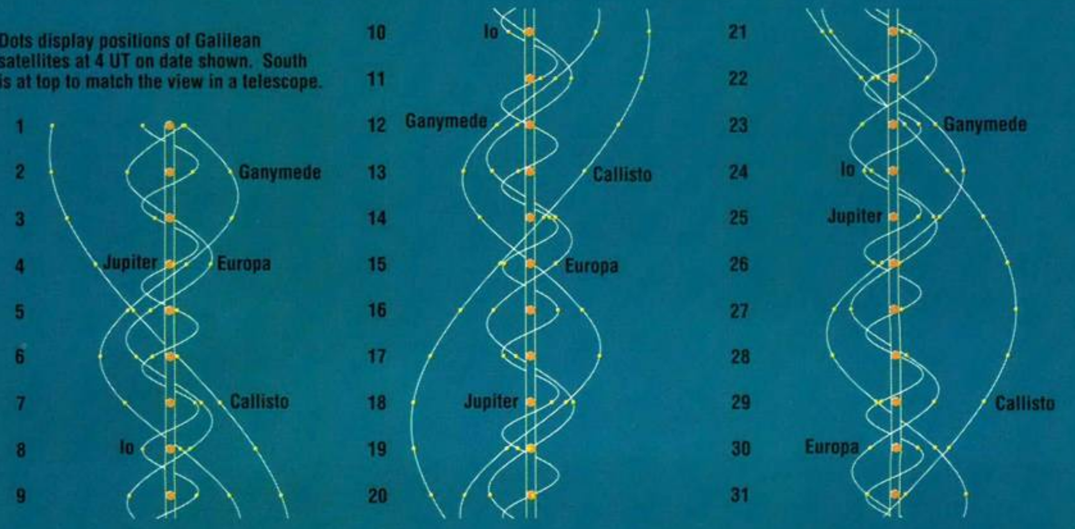
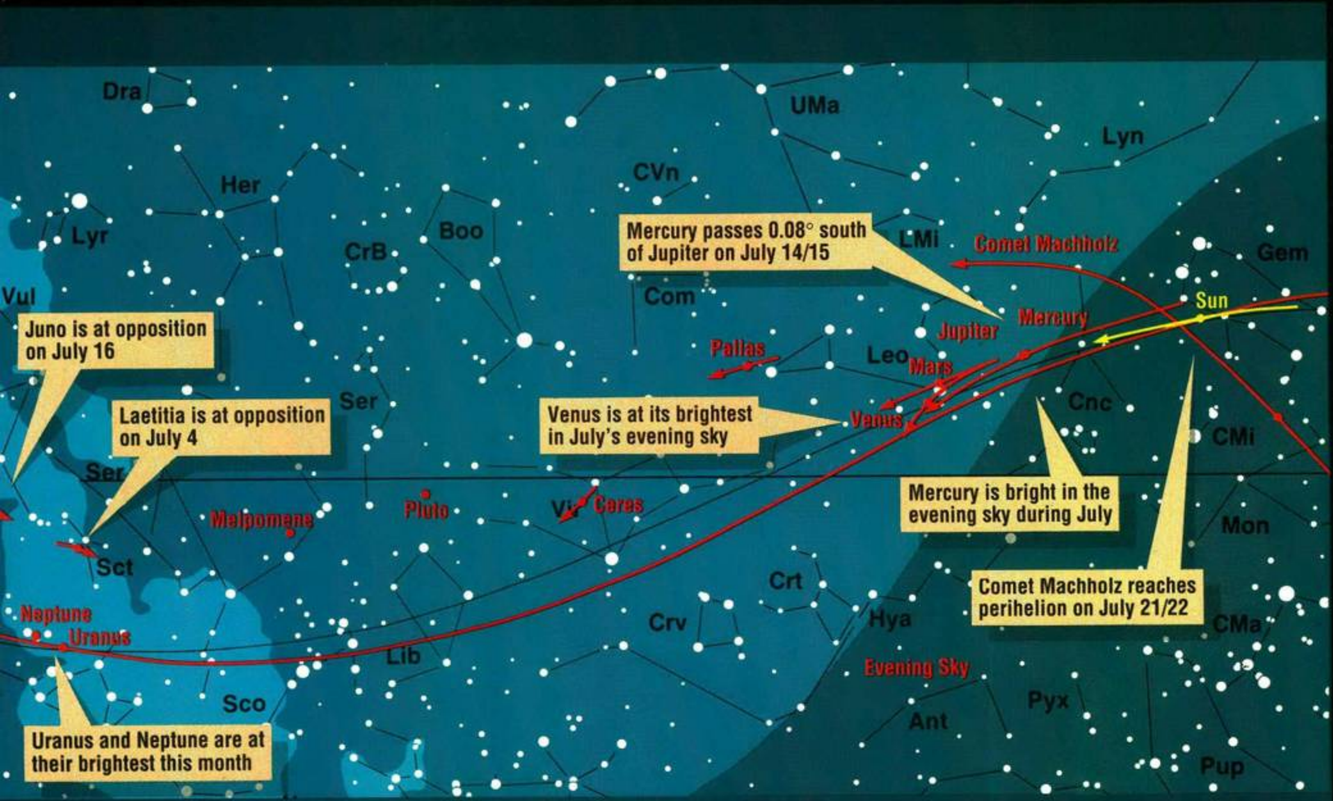


Planet	MERCURY	MERCURY	VENUS	VENUS
Date	July 1	July 31	July 1	July 31
Magnitude	–0.8	+0.8	–4.4	–4.4
Angular Size	5.5″	8.7″	29.3″	46.5″
Illumination	83%	36%	39%	14%
Distance (AU) from Earth	1.221	0.777	0.570	0.359
Distance (AU) from Sun	0.364	0.467	0.725	0.728
Right Ascension (2000.0)	7h45.9m	10h18.2m	9h42.1m	10h30.3m
Declination (2000.0)	23°09′	8°09′	14°40′	4°59′

Jupiter's Moons

Dots display positions of Galilean satellites at 4 UT on date shown. South is at top to match the view in a telescope.

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Ceres
Melpomene
Mon
Sct
Crt
Neptune
Uranus
Crv
Hya
CMa
Lib
Evening Sky
Sco
Pyx
Ant
Pup

Mercury passes 0.08° south of Jupiter on July 14/15

Juno is at opposition on July 16

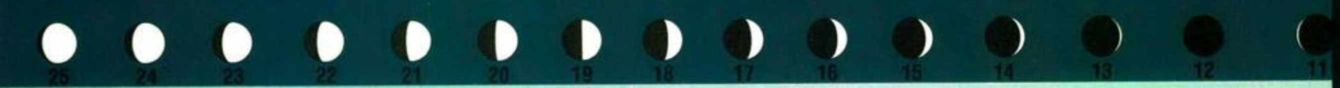
Laetitia is at opposition on July 4

Venus is at its brightest in July's evening sky

Mercury is bright in the evening sky during July

Comet Machholz reaches perihelion on July 21/22

Uranus and Neptune are at their brightest this month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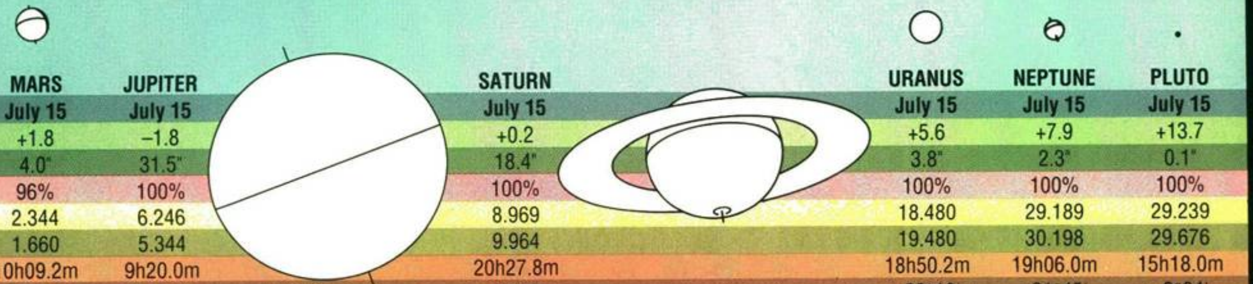
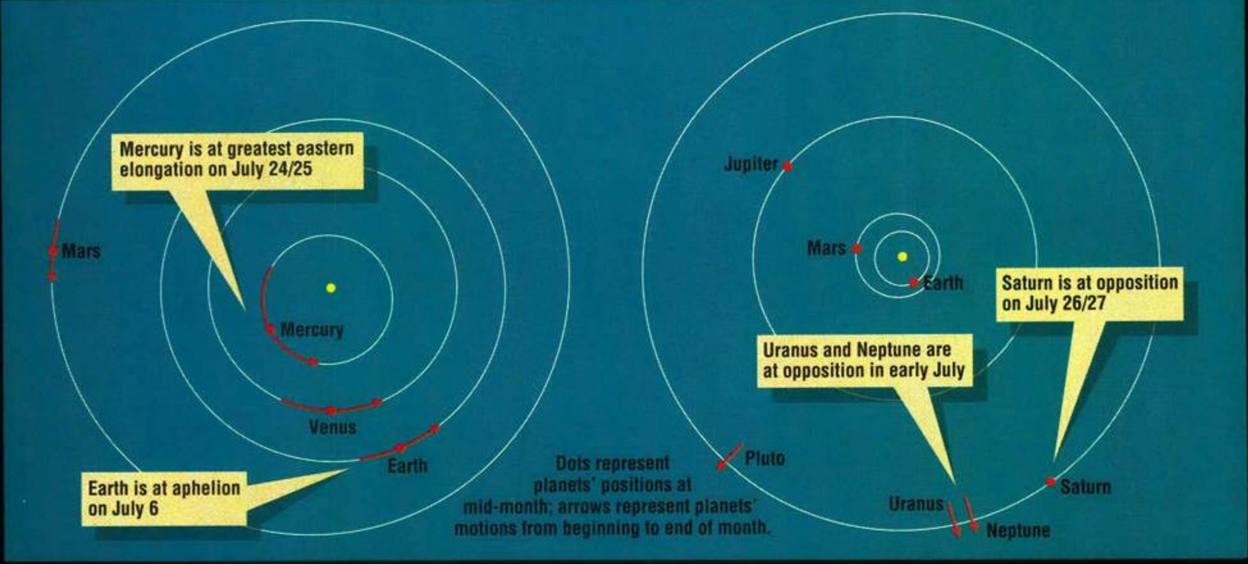


MARS	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
July 15	July 15	July 15	July 15	July 15	July 15
+1.8	−1.8	+0.2	+5.6	+7.9	+13.7
4.0"	31.5"	18.4"	3.8"	2.3"	0.1"
96%	100%	100%	100%	100%	100%
2.344	6.246	8.969	18.480	29.189	29.239
1.660	5.344	9.964	19.480	30.198	29.676
10h09.2m	9h20.0m	20h27.8m	18h50.2m	19h06.0m	15h18.0m
12°35'	16°21'	−19°35'	−23°19'	−21°45'	−2°24'

The Planets in Their Orbits


Mars
Mercury
Venus
Earth
Jupiter
Mars
Earth
Pluto
Uranus
Neptune
Saturn

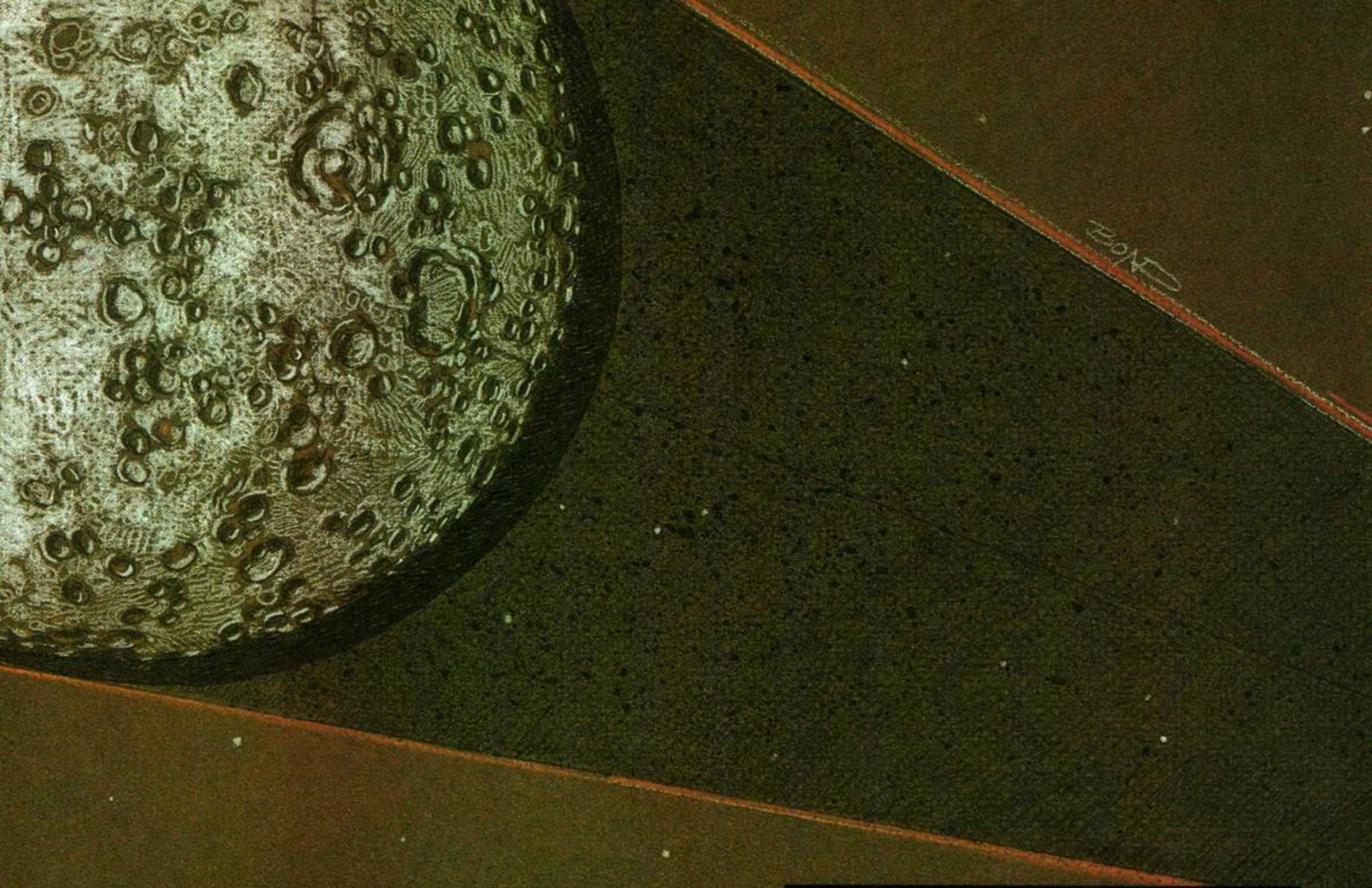
Mercury is at greatest eastern elongation on July 24/25

Earth is at aphelion on July 6

Dots represent planets' positions at mid-month; arrows represent planets' motions from beginning to end of month.

Uranus and Neptune are at opposition in early July

Saturn is at opposition on July 26/27



THIRD CONTACT
February 26, 1979 by William Sterne

On July 11 at 6:23 a.m. local time, a finger of darkness will sweep down from space and touch the surface of Earth. The Moon will come between Earth and the Sun and begin casting its shadow onto the planet below.

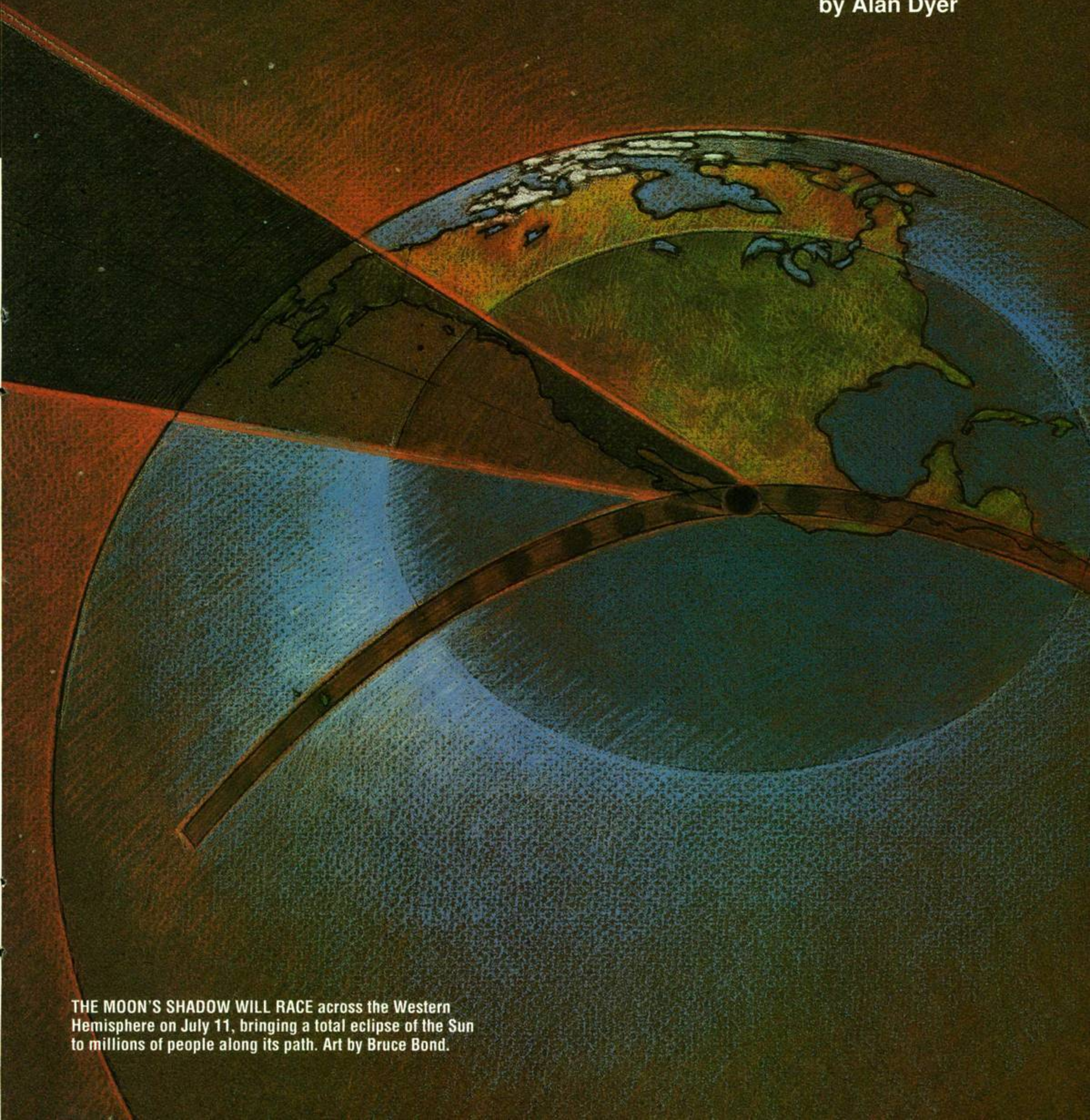
From its contact point at sunrise in the mid-Pacific, the lunar shadow will race eastward across the ocean at over 5,000 miles per hour. For four brief minutes, the zone of darkness will engulf the island of Hawaii and then move on. Just before noon, local time, the Baja Peninsula and the west coast of Mexico come under the fast-moving shadow.

For the next two hours, the 160-mile-wide shadow will travel down the length of Mexico, across parts of central America, and into South America.

When Worlds Align

On July 11 the Sun, Moon, and Earth align to produce the first total eclipse of the Sun visible from North America since 1979.

by Alan Dyer



THE MOON'S SHADOW WILL RACE across the Western Hemisphere on July 11, bringing a total eclipse of the Sun to millions of people along its path. Art by Bruce Bond.

Diagram to Scale

At sunset in a remote section of Brazil, the Moon's shadow will lift back into space. In all, the shadow sweeps eastward across the globe for some 3 hours and 20 minutes, crossing some of the world's most populous cities and giving tens of millions of people a chance to view a rare celestial phenomenon — a total eclipse of the Sun.

For many traveling to the eclipse path, whether it be to Hawaii, to the southern tip of Baja, or to one of the sites in mainland Mexico, July's eclipse will be their first opportunity to stand in the Moon's shadow. Drawn by the impassioned tales of the eclipse experience told by veteran shadow chasers, the first-timers will soon realize that no description, no matter how poetic or detailed, can impart the emotional impact of seeing the Sun disappear from the daytime sky.

To experience the drama, hundreds of thousands of people from every continent will converge on the eclipse path. Millions more will elect to stay home on eclipse day, away from the dark central path of the Moon's shadow, but still within its lighter outer boundaries. For them, July 11 will bring a partial eclipse of the Sun.

Chances are you'll be one of those eclipse watchers. Although your day will be less dramatic, it can still be memorable. Even a partial eclipse provides a fascinating example of what happens when worlds align.

Once in a Lifetime

If you see just one total eclipse in your life, consider yourself fortunate. But eclipses of the Sun are actually quite common — celestial mechanics dictates that there be at least two solar eclipses somewhere on Earth each year. There can be as many as five in a year, though this is rare. The last quintuple-eclipse year was 1935; the next will be 2206. (The year 2000 comes close with four eclipses, all of them partials.)

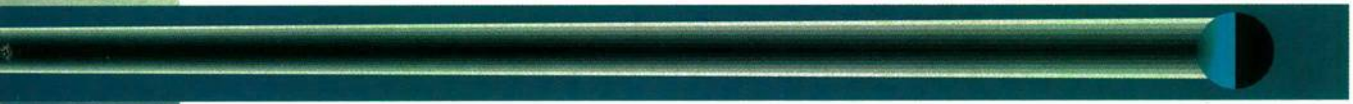
The catch is that in each year's allotment of solar eclipses not all are total — those in which the Moon completely covers the Sun's disk. Some are partial-only eclipses. In these events the center of the Moon's shadow passes above Earth's north pole or below the south pole; the outer regions of the shadow graze Earth's northern or southern latitudes. People at those latitudes see the Moon partially hide the Sun.

Other eclipses are annular. During these eclipses the Moon slides directly across the center of the Sun, but the lunar disk appears smaller than the Sun's disk. At mid-eclipse the Sun is reduced to a ring of sunlight.

A fourth type of solar eclipse is a hybrid of the annular and total. The Moon's shadow reaches the surface of Earth, creating a total eclipse, but only in the middle of the shadow's track. Near the eastern and western ends of the path, the shadow doesn't quite touch the surface. Viewers there see an annular eclipse. The next such eclipse is April 8, 2005, in the Pacific. The last such hybrid eclipse was in 1987, though eclipse fans will remember the May 30, 1984 eclipse in the southeast United States. It was technically just an annular eclipse but it came within a hair's breadth (or a lunar mountain height) of being total at the center of the eclipse track.

Of the four types of solar eclipses, annular/totals are statistically the rarest and partials the most common. For example, in the 11 years from 1990 to 2000, there are 10 partial-only eclipses, 8 totals, 7 annulars, and no annular/total combos. During that stretch of time, total eclipses occur on average every 16 months, a fairly typical frequency for total eclipses. Why then are they billed as once-in-a-lifetime events? It's not because of rarity in time, but in space.

To see a total eclipse you must be in the dark central portion of the Moon's shadow, called the umbra. At best, this umbral shadow is a circle only 200 miles across. During a typical eclipse, it will trace a path



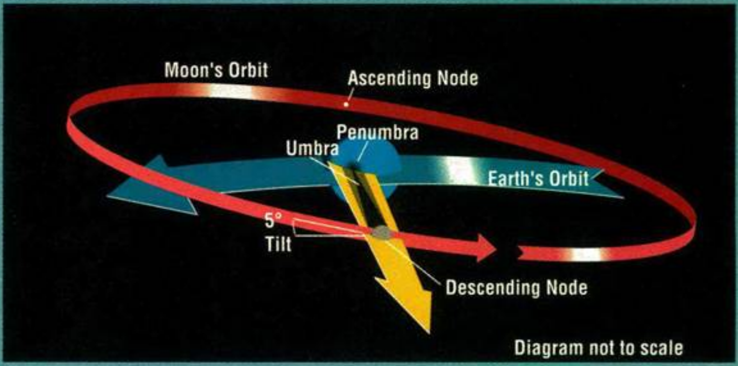
THE TRUE LENGTH of the Moon's shadow is surprising. This diagram shows the size of the Earth and Moon and the distance between them on the same scale, about 1,100 kilometers per millimeter.

MULTIPLE SUNS across the sky record the sequence of a partial solar eclipse that resembles what many in the United States will see July 11. Photo of the December 13, 1974 partial eclipse by Richard Pini.

several thousand miles long. While it may cover a sizable stretch of surface area, chances are most of it will be ocean or remote areas of land. The statistical average is that any given location on Earth will see a total eclipse only once every 350 years. If you allow yourself the freedom to travel as far as 1,000 to 2,000 miles to see an eclipse, then the once-in-a-lifetime rule is closer to the mark. Eclipse chasers up the odds by traveling to the far corners of the world every couple of years. In the last decade, eclipse chasing took the hard-core enthusiasts to locations such as Siberia, Indonesia, Borneo, and the Philippines. The rest of us stayed home, patiently awaiting 1991.

And a long wait it's been. The last total eclipse on North American soil was February 26, 1979. Many readers will remember braving the cold winter winds of Montana, Saskatchewan, and Manitoba for 2 1/2 minutes of totality. The long drought of home-soil eclipses has created a thirst for the eclipse experience among North American amateur astronomers. And what a way to end the drought! With 6 minutes and 56 seconds of totality at the eclipse path's midpoint, July's eclipse will be the longest until June 13, 2132. It is only 12 seconds shy of the longest eclipse of the 20th century which

WHEN MOON AND SUN MEET



To show the Earth, Moon, and lunar orbit together, most eclipse diagrams (such as the one directly above) can't be drawn to scale. From these, you might get the impression that the Moon should cast its shadow onto Earth every month at New Moon.

But this is far from the case. The scale diagram across the top of these two pages gives you a better idea why. The Moon's shadow is in fact a very long and narrow cone. If the Moon is precisely between Earth and the Sun, the apex of this cone will touch Earth. But if, as the Moon comes between us and the Sun, the Moon passes as little as half a degree above or below the Earth-Sun line, the shadow will miss Earth altogether. In most months, this is indeed what happens.

The Moon's orbit is tilted 5° with respect to the plane of Earth's orbit around the Sun. This creates two special spots on the Moon's orbital path — two "nodes" as they are called — where the lunar orbit intersects the Earth's orbit. Twice each year (during an "eclipse season") the Moon's orbit is oriented as it is shown above. The nodes are lined up so they lie along the Earth-Sun line. If the Moon also happens to wander between the Earth and Sun at this time, we get some type of solar eclipse.

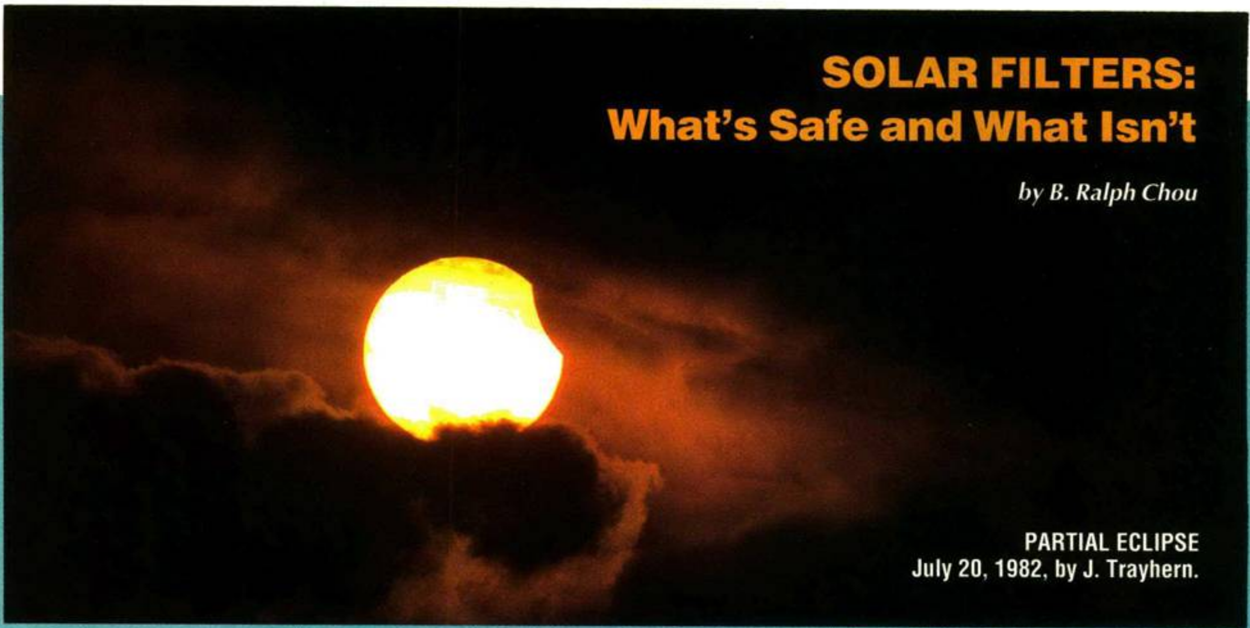
PARTIAL ECLIPSE, taken October 3, 1986, by Angus Thomson.

ANNULAR ECLIPSE, taken May 30, 1984, by Ed Leikam and Dewey Vanderhoff.

It might just be a partial eclipse — only the lighter penumbral shadow strikes Earth. Or if the Moon is at the far point in its monthly orbit, its umbral shadow will stop short of Earth's surface. From our vantage point, the lunar disk appears too small to completely cover the Sun and we see an annular eclipse. Such an eclipse occurs across the United States on May 10, 1994. Only less than 30 percent of the time do we get a total eclipse.

SOLAR FILTERS: What's Safe and What Isn't

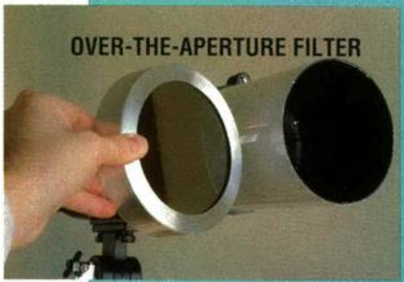
by B. Ralph Chou



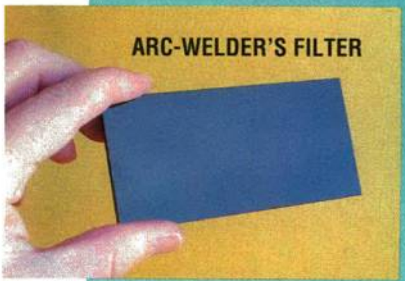
PARTIAL ECLIPSE
July 20, 1982, by J. Trayhern.

Looking directly at the Sun, either during the partial phases of an eclipse or at any other time, can be extremely dangerous. Without any optical aid the retina of an unprotected eye can be burned in as little as 30 seconds. With the extra light-gathering ability of a telescope or binocular, a burn takes only a fraction of a second. Because the retina of the eye has no pain sensation, this injury occurs painlessly, and the visual effects of the burn will not appear until hours after the damage has been done.

Over the years a variety of materials have been recommended for safe solar viewing. Many have been proven unsafe. Layers of exposed and developed black-and-white film are often touted as safe. However, if the emulsion is not silver-based, as is the case with some new black-and-white films, even the blackest negatives still transmit dangerous levels of infrared radiation. The same is true of the black leader from rolls of color slide film. Since there are too many variables, the best bet is to stay away from any kind of film.



OVER-THE-APERTURE FILTER



ARC-WELDER'S FILTER

Other dangerous filters include smoked glass, x-ray film, black plastic garbage bags, sunglasses, crossed polarizing filters, and photographic neutral density filters — even those with a density of ND5. All reduce the amount of visible light but fail to filter out infrared radiation, which can also burn the eye.

Another very dangerous product is the "sun filter" that comes with many imported telescopes. This filter is designed to screw onto the bottom of an eyepiece, a location that subjects the filter to intense heat build-up. As a result, the glass filter cracks and lets through the full force of the Sun's light.

The safest method to watch the eclipse is by projecting the Sun's image (see page 70). This is also the best procedure for showing the eclipse to groups, especially children. For those who are more familiar with solar viewing and who wish to view the partial eclipse directly with the unaided eye, an excellent filter is a #14 arc-welder's glass. This dark green glass filters out all ultraviolet and infrared radiation and reduces the amount of visible light by a factor of approximately 370,000. It is sold at welding supply stores in pieces approximately 2 by $4\frac{1}{4}$ inches, large enough to cover both eyes at once. Lighter shades, such as a #12, are too bright. I do not recommend them.

Another type of safe solar filter is available from companies such as Celestron International, Thousand Oaks Optical, and Roger W. Tuthill Inc. These filters use a plastic Mylar sheet that has been coated with a layer of aluminum. Though they render the Sun a cool blue-white, the image quality through these filters is acceptable for both visual and photographic use. Aluminized Mylar filters come in sizes to fit over the front of most telescopes or binoculars. (Be sure to cap the front lens of any finderscopes so no light can get through.) Do NOT use aluminized mylar sold as "space blankets" or as heat-retaining film for windows. This Mylar is too flimsy and not optically dense enough to be safe.

A more expensive option is to use a glass solar filter over the front of the telescope. These over-the-aperture filters feature a vacuum-deposited layer of Inconel (an alloy of nickel and chromium) or a mixture of stainless steel and Inconel. The image is a yellow-to-orange color. The only manufacturer of glass filters for the amateur astronomy market is Thousand Oaks Optical.

To request a free brochure on safe solar viewing tips being distributed by a coalition of eye safety organizations, call toll free (800) 221-3004 (U.S. only).

After over 20 years of solar observation and eclipse chasing, what do I use? I have used over-the-aperture filters of both Mylar and optical glass for photography through telescopes and camera lenses and #14 arc-welder's glass for visual observations. Each has a place in my equipment case; each gives me a different but safe view of one of nature's grandest celestial events.

B. Ralph Chou is a professional optometrist with the University of Waterloo, Ontario, who has tested solar filters extensively over the years.

occurred on June 20, 1955, in the Indian Ocean. On July 11, parched eclipse fans will be able to shower themselves in the sight of the totally eclipsed Sun.

How to Build an Eclipse

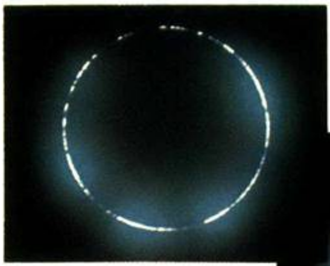
Several factors converge to make July's eclipse an extra long one. To make a long eclipse you need the shadow of the Moon to be large and slow-moving.

Having the shadow fall near the equator helps slow down the shadow with respect to the surface of Earth. (At its midpoint, the path of July's eclipse is only 22° north of the equator.) As Earth spins on its axis, points on the surface near the equator travel the fastest. Because the circumference of Earth is about 25,000 miles and the day is 24 hours long, sites at the equator whiz around at over 1,000 miles per hour. Locations farther north or south have a smaller circumference to sweep out each day and so travel slower.

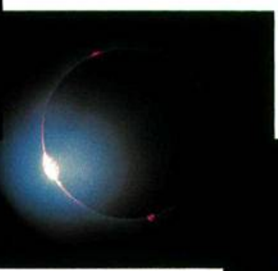
During an eclipse, the Moon's shadow sweeps across space from west to east at over 2,000 miles an hour. If it passes over an equatorial spot on Earth, the high rotation velocity allows the site to keep up with the Moon's shadow more easily than a site at more temperate latitudes can. In the case of July's eclipse, as it passes over Baja and the west coast of Mexico, the shadow is traveling 1,300 miles per hour with respect to the ground. This is slow for an eclipse. The 160-mile diameter shadow takes nearly 7 minutes to pass a point on the Mexican west coast.

The next ingredient for a long eclipse is that it must occur near noon. (At Mazatlán the eclipse begins at 11:59 a.m. local standard time.) The shadow is then perpendicular to Earth's surface. The west-to-east motion of the Earth parallels the west-to-east motion of the shadow. Near the western and eastern ends of the path where the eclipse is seen after sunrise or before sunset, the shadow strikes Earth's surface obliquely. The rotation of Earth contributes little to slowing the ground speed of the shadow. The shadow is longer but traveling much faster, over 5,000 miles per hour. That's why in Hawaii and Brazil, despite their low latitudes, the eclipse lasts four minutes or less.

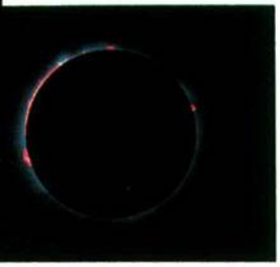
The longest eclipses can occur only in late June or early July. In the first week of July each year, our planet is farthest from the Sun, a point called aphelion. This means the Sun's disk is at its smallest apparent



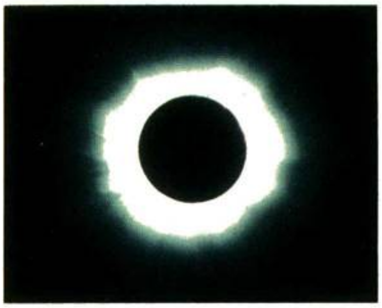
BAILY'S BEADS
March 29, 1987 annular eclipse, by Robert May.



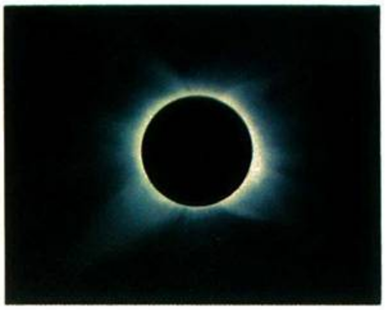
DIAMOND RING
June 11, 1983, by Jacques Guertin.



PROMINENCES
June 11, 1983, by Jacques Guertin.



CORONA NEAR SOLAR MINIMUM
March 18, 1988, by Roger Tuthill.



CORONA NEAR SOLAR MAXIMUM
June 11, 1983, by Huguette Guertin.

A POCKET CHECKLIST
TO ECLIPSE PHENOMENA, IN THIS ORDER . . .

PARTIAL PHASES

1. **Moon Covering Sunspots**
2. **Projected Crescents**
3. **Sharp Shadows**
4. **Darkening of Sky**
5. **Drop in Temperature**

PRIOR TO 2nd CONTACT

1. **Shadow Bands**
2. **Baily's Beads**
3. **Moon's Shadow Approaching**
4. **Diamond Ring**

TOTALITY

1. **Chromosphere**
2. **Prominences**
3. **Coronal Structures**
4. **Twilight Glows**
5. **Planets and Stars**

3rd CONTACT & LATER

1. **Diamond Ring**
2. **Moon's Shadow Receding**
3. **Baily's Beads**
4. **Shadow Bands**

diameter for the year. At July's eclipse the Sun's disk is 31'27" across. (By comparison, in January when Earth is closest to the Sun, the solar disk is 32'31" across.) A small solar disk means the Moon can cover it for longer.

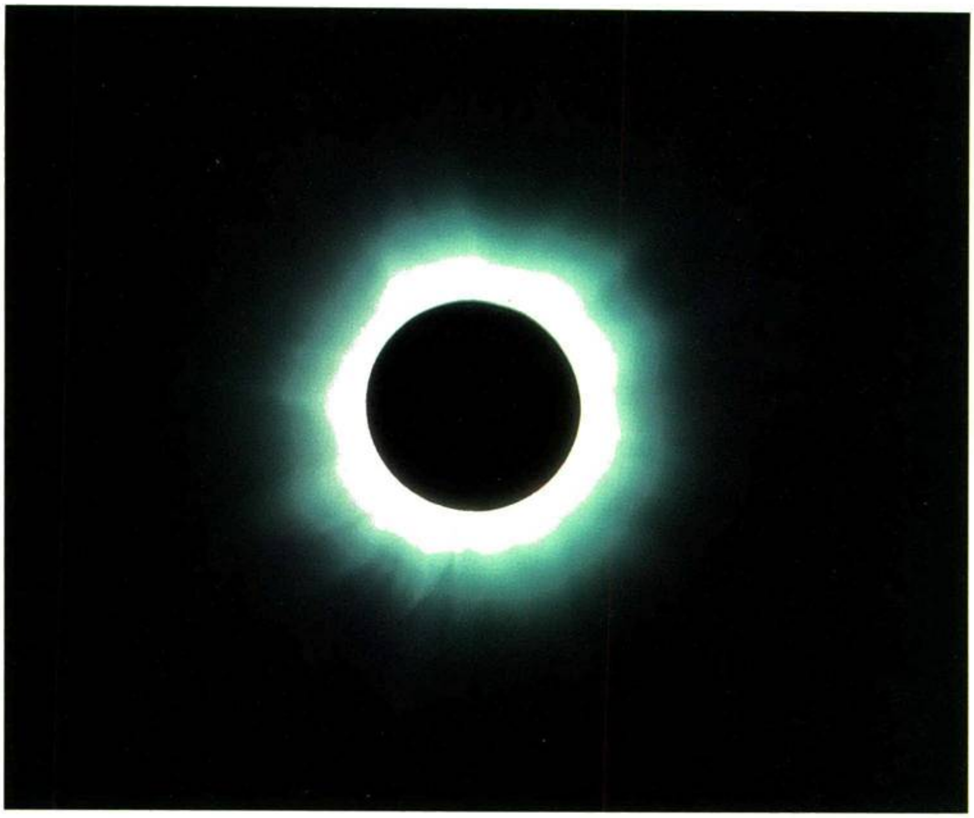
Not only does the time of the year and hour of the day affect the length of totality, but so does the time of the month. The longest eclipses occur when the Moon is near perigee, the point in its elliptical orbit closest to Earth. July's eclipse fortuitously falls only 9 hours after perigee. The Moon's disk will appear as large as it gets for the month, 33.4' across, 14 percent larger than when it is farthest from Earth on the other side of its orbit. Like the smaller Sun, the larger Moon increases the size of the Moon's shadow where it hits Earth. A final bonus is that July's perigee is the closest of the 13 perigees in 1991. On July 11 the Moon will appear not only as large as it gets for the month but also for the entire year.

The result of this celestial dance by the Sun and Moon is that on eclipse day the disk of the Moon will be 6.2 percent larger than the solar disk. This doesn't sound like a great difference, but it's enough to significantly lengthen the time the Sun remains hidden behind the Moon. It's also enough to affect many of the types of phenomena you'll see during totality.

Countdown to Totality

The sequence of a typical 2- to 3-hour solar eclipse is divided into "contacts." First contact is when the Moon takes its first detectable bite out of the Sun. Second contact is the big event, when the last shaft of sunlight disappears behind the Moon and totality begins. A few short minutes later, an explosion of light appears on the other side of the Moon and the Sun re-emerges. This is third contact. The eclipse now plays itself out in reverse. Fourth contact occurs when the last bit of the Moon clears the Sun and the two worlds part company. A lot happens between first and fourth contacts, much of it very quickly. Unless you know what to look for, you could miss a great deal.

First Contact: The Moon Encroaches — A shout goes up from some watchful soul, "There's the Moon! I see it! First contact!" People rush to their telescopes or binoculars to confirm the sighting. Then everyone checks their watch to see if first contact occurred on time (it always does), just to reassure themselves that the universe really is unfolding as it



SLOW FILM AND A TELEPHOTO LENS will capture the corona very well. On February 16, 1980, Rick Dilsizian used a 500mm f/8 lens and Kodachrome 64 film for a 1-second exposure.

A POCKET EXPOSURE GUIDE

With ISO 64 film at ...	f/4	f/8	f/16	My System
Partial Phases (with solar filter)	1/500	1/125	1/30	....
Diamond Ring (no filter)	1/2000	1/500	1/125	....
Inner Corona (no filter)	1/250	1/125	1/15	....
Outer Corona (no filter)	1/15	1/4	1 sec.	....

For closeups of the eclipsed Sun, use at least a 300mm telephoto lens. Slower, fine-grained film is best. For wide-angle shots of the darkened sky at totality, use 1- to 10-second exposures at f/2.8 with ISO 64 film. For partial phases, take test shots before eclipse day through your filter to determine correct exposures. For more details on eclipse photo techniques, see "How to Photograph the Eclipse," April 1991 ASTRONOMY.

should. The eclipse has begun. The excitement now lies in the heightened anticipation of what lies ahead.

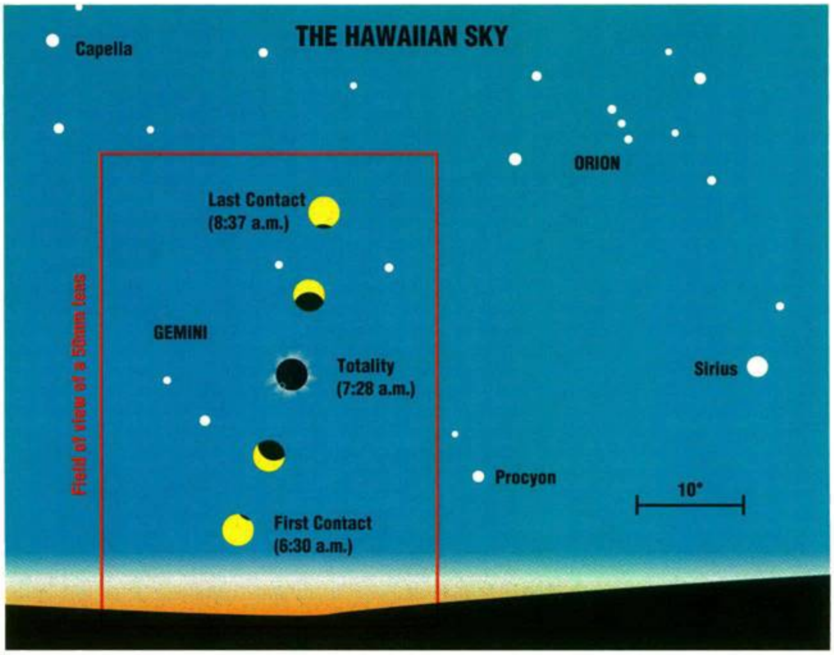
At first contact the Moon's bite will appear on the west side of the Sun. From Mexico that will be the right-hand side of the Sun; from Hawaii it will be the top of the Sun. From now until second contact, the Moon slides from right to left across the Sun's disk (Mexico) or from top to bottom (Hawaii). This motion is almost entirely due to the Moon's orbital revolution around Earth.

For the first half of the partial eclipse, nothing outwardly betrays the fact that an eclipse is underway. But after 50 percent of the Sun is covered, the day begins to grow darker. The difference is subtle at first, and the onset of darkness very slow. From this point on, with the sunlight coming from a smaller and smaller source in the sky, shadows look sharper. Gradually the lighting begins to look strange. Glints of sunlight off water look even more sparkly than usual.

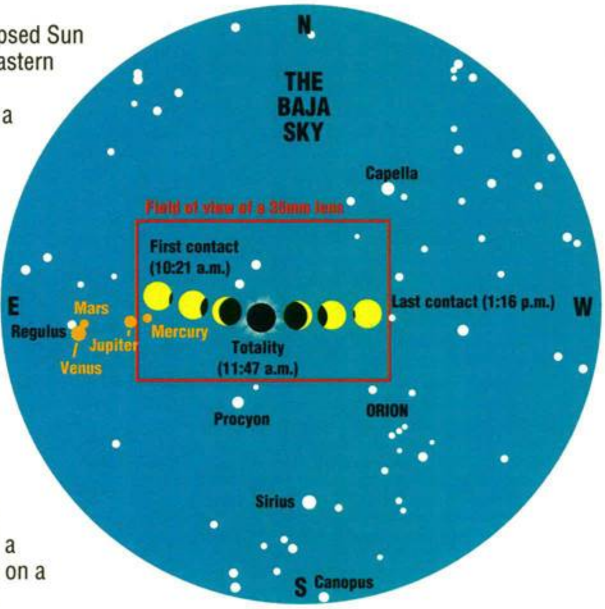
As the Sun approaches a crescent phase, look for images of the Sun projected on the ground from nearby trees (if there are any at your observing site). The openings between leaves (or palm fronds) act as natural pinholes projecting hundreds of little eclipsed Suns on the ground below.

T – 4 minutes: Shadow Bands Rippling — With four minutes to go, the day has taken on the gloom of a premature dusk. What is left of the Sun is a small but brilliant source of light in the ever-darkening sky. In the minutes leading up to totality, with the Sun reduced to a sliver, watch for bands of light and dark rippling very quickly across the ground. You'll see them best against smooth white surfaces. Some people lay out sheets on the ground for the purpose of catching these subtle shadow bands.

The origin of shadow bands has been debated for years. Some feel they are an interference effect. The light waves from the thin slit of the crescent Sun interfere with one another, canceling each other out (creating dark bands,) or adding together (creating bright bands) with the atmosphere providing the turbulence necessary to break up the incoming light into mutually interfering beams. Others feel the shadow bands are simply the shadows created by atmospheric turbulence, like the patterns of light at the bottom of a swimming pool. In either case, shadow bands seem to be a frequent phenomenon at long eclipses. They'll almost certainly appear at this one.



FROM HAWAII the eclipsed Sun will be 22° above the eastern horizon. The shaded rectangle is the field of a 50mm lens on a 35mm-format camera.



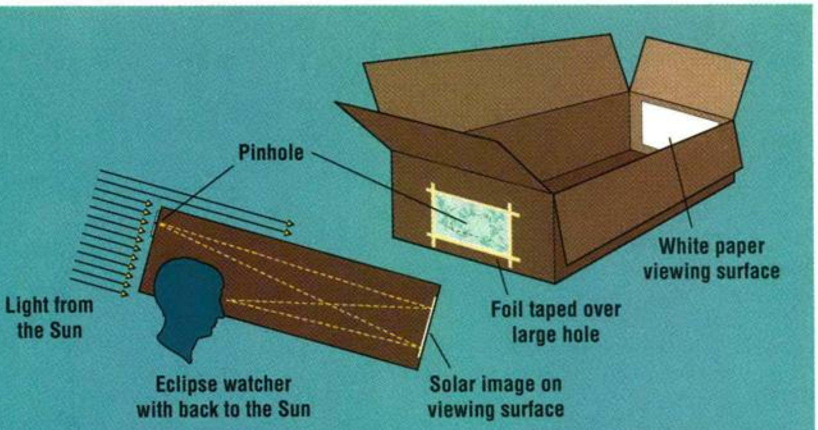
FROM MEXICO the eclipsed Sun will be at the zenith. The shaded rectangle is the field of a 35mm wide-angle lens on a 35mm-format camera.

T – 30 seconds: Baily's Beads — In the final seconds before totality the solar crescent shrinks to a rim of light along the advancing limb of the Moon. This rim may break up into brilliant dots as the last vestiges of sunlight shine through lunar valleys and craters. The edge of the Moon becomes a shimmering necklace of solar jewels. Named after a 19th-century astronomer who described them, Baily's beads are a short-lived feature of most eclipses. But at this eclipse they may not appear at all. The reason is the size of the lunar disk. It will cover up the last sliver of Sun very quickly. If you are located at a site north or south of the centerline, the Moon's disk will be off-center. Totality will be shorter but you stand a greater chance of seeing Baily's beads.

T – 15 seconds: Moon Shadow Rising — Immediately before totality tear yourself a way from the shrinking Sun. Look to the west. You'll see a wall of darkness rising up the sky. This is the Moon's shadow bearing down on you at supersonic speed. Just as the wall reaches the Sun, totality begins. The sheer speed of the coming of darkness just prior to second contact is one of the most impressive phenomena of a total eclipse.

T – 5 seconds: Diamond Ring — At this point the eclipsed Sun often appears as a single brilliant jewel set on a ring of ghostly light. This is the diamond ring effect, created as the

PROJECTING THE SUN


Pinhole
Light from the Sun
Eclipse watcher with back to the Sun
Foil taped over large hole
White paper viewing surface
Solar image on viewing surface

For group viewing situations or for those without access to the special filters recommended on page 66, a safe eclipse viewing method is solar projection. You don't even need any optics. A pinhole punched in a sheet of aluminum foil and placed over a hole at one end of a cardboard box will project an image of the partially eclipsed Sun onto the other end of the box (place a white card there to act as a screen). The size of the image will be 1/115 the distance between the pinhole and the screen. Holding the box over your head will shade the projection screen. Kids will love it *and* it keeps them occupied looking in the opposite direction from the Sun. Remember, the idea is to look at the projected image of the Sun, NOT to look through the pinhole.

Using a small telescope or a pair of binoculars, you can also project a focused image of the Sun onto a white screen held a few inches behind the eyepiece. If you are using a telescope use a low-power eyepiece and stop-down the aperture to only one or two inches across. Do not attempt this with Schmidt-Cassegrain or Maksutov telescopes; the heat build-up inside could damage the secondary mirror. Be sure to cover finderscopes or, in the case of binoculars, one half of the optical pair. Aim the instrument at the Sun by adjusting the tube until it makes the smallest possible shadow on the ground. Although safe, a solar projection setup should never be left unattended; an unsuspecting person might try to look through the telescope.

If you don't want to fuss with filters and solar projection rigs but still want to witness the eclipse, then contact your local planetarium or science center. Many will be organizing eclipse viewing sessions for the public on July 11.

last bit of the Sun's surface shines through a cratered gap on the Moon's limb. It lasts only a few seconds. Photographers need to be very quick. To capture it on film remove any solar filter you have on your telescope or lens.

T = 0 seconds: Second Contact — It is now safe to look at the eclipse without any filter. When the last glint of sunlight disappears behind the dark disk of the Moon, the real show begins. This is what you have come for. Around you all will be quiet, except for the clicking of shutters and the whispered gasps of amazement.

T + 5 seconds: Chromosphere — If you are observing with a telescope you may see a vivid red glow along the advancing edge of the Moon at this point. The glowing photosphere of the Sun is now gone, but the layer of the Sun's atmosphere just above it is still visible. But not for long. This layer, called the chromosphere, shines in the light of hydrogen atoms which is dominated by a bright emission line in the red part of the spectrum. At best the chromosphere will be visible for only a few seconds before it, too, disappears behind the Moon.

T +10 seconds: Prominences — You may see red flames jutting out from the chromosphere. These are prominences — tongues of gas arcing above the chromosphere. During short eclipses, prominences are often visible all around the disk throughout totality. At this eclipse you'll likely see them only at the beginning and end of totality. At mid-eclipse, with the Moon centrally positioned over the Sun, the lunar disk will be large enough to hide all but the most far-reaching prominences.

T + 30 seconds: Corona — The corona is what makes a total eclipse the spectacle it is. It appears as soon as totality begins. But with everything else to take in at second contact, you may not notice it until seconds later. For one thing, it will take a few moments for your eyes to adjust to the darkness. But when they do, the full glory of the corona will appear to blossom like a flower around the dark disk of the Moon.

The corona is the Sun's outer atmosphere. It is a very tenuous gas that glows with an opalescent light unlike anything you've seen. Look for loops and swirls in the corona, for structure that looks like brushstrokes, for streamers stretching off into the black surrounding sky — the corona is painted with delicate details that photographs seldom capture.

The appearance of the corona varies with each eclipse. At solar minimum, the corona looks round, symmetrical, and uniform. But this year, with the Sun just past the peak of activity in its 11-year cycle, the corona will be rich in structure, with streamers and plumes reaching out in all directions. There will be enough detail to keep you hypnotized for the entire length of totality. But look around — there's much more to see.

T + 2 minutes: A 360° Sunset — Two minutes of gazing at the corona should lock most of its features firmly in your mind. Now look away and scan all around the horizon. You should see an orange glow stretching for 360° around the horizon. This wrap-around twilight is from light outside the umbral shadow zone. From Mexico it provides a perfect frame for the dark sky overhead punctuated by the black hole of the eclipsed Sun straight above you.

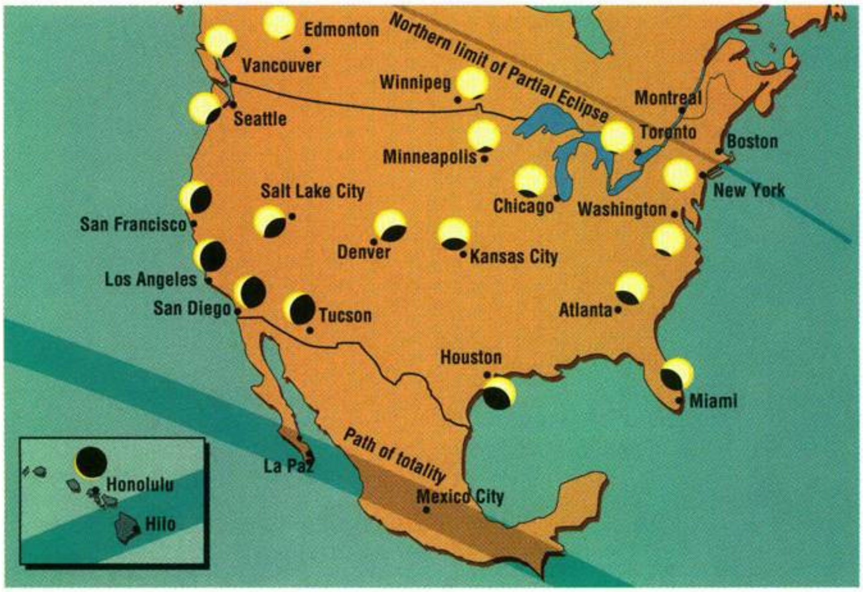
T + 2 minutes: Planets and Stars — While you're taking the wide view of the scene, look for stars and planets. Since this is a long eclipse, the sky will get very dark at mid-totality, allowing you to see stars down to at least first magnitude with the naked eye.

From Hawaii, though, you won't be able to see any planets during totality — they're all below the horizon. But it should be easy to pick out bright stars: Sirius, Procyon, Capella, and the brightest stars of Orion and Gemini. In fact, the constella-

ECLIPSE TIMES — JULY 11

City	Start	Mid	End	%
PARTIAL ECLIPSE SITES				
Atlanta	2:30	3:31	4:29	28%
Chicago	1:28	2:16	3:01	13%
Denver	**11:43**	12:50	1:56	37%
Edmonton	12:04	12:34	1:04	3%
Honolulu	**6:31**	**7:29**	**8:35**	96%
Houston	12:59	2:18	3:32	60%
Kansas City	1:07	2:08	3:08	28%
Los Angeles	**10:12**	**11:27**	12:47	69%
Miami	2:41	3:49	4:51	43%
Minneapolis	1:19	2:04	2:49	11%
New York	3:09	3:34	3:59	2%
Salt Lake City	**11:32**	12:38	1:45	39%
San Diego	**10:12**	**11:30**	12:51	74%
San Francisco	**10:11**	**11:20**	12:33	55%
Seattle	**10:32**	**11:22**	12:14	19%
Toronto	2:57	3:24	3:51	2%
Tucson	**10:23**	**11:43**	1:04	72%
Vancouver	**10:35**	**11:22**	12:09	15%
Washington	2:55	3:33	4:10	7%
Winnipeg	1:22	1:55	2:27	4%
TOTAL ECLIPSE SITES				**Duration**
Hilo	**6:30**	**7:30**	**8:38**	4m07s
La Paz	**10:23**	**11:50**	1:18	6m26s
Mazatlán	**10:32**	12:01	1:28	5m41s
Mexico City	**11:54**	1:24	2:47	6m42s
San Jose del Cabo	**10:24**	**11:53**	1:21	6m25s
V. Insurgentes	**10:19**	**11:46**	1:13	2m15s

All times in the local time zone, with Daylight Saving Time added where applicable. Times in **boldface** are a.m.



A PARTIAL ECLIPSE will be visible over most of North America, with sites farther south seeing more of the Sun covered by the Moon. Illustration by Steve Davis.

tions above you now are the constellations you associate with winter. Six months from now the Sun will be in the opposite half of the sky and these constellations will be visible at night. But for now, this is your only chance to see Orion in the daytime in July!

From Mexico, with the Sun directly overhead, you can see not only stars at midday but also four planets. Venus will be easy. It will be 41° east of the Sun. Next to it will be 1.8-magnitude Mars and the star Regulus, shining at magnitude 1.3. Both will be less than 1 percent as bright as –4.5-magnitude Venus. In between that trio and the Sun look for another pair of planets: –1.8-magnitude Jupiter and –0.1-magnitude Mercury.

For those on the island of Hawaii, two minutes into totality means the eclipse is half over. For those in Mexico, relax. You have nearly five minutes left to bask in the glow of the corona. The time will pass very quickly. All too soon a burst of sunlight explodes on the trailing edge of the Moon.

Third Contact: Here Comes the Sun — No one really wants totality to end, but the sight of the Sun returning sets off an instinctive shout of celebration from everyone who sees it.

Amid the cheering and congratulations you're probably paying little attention to the eclipse. But wait! The phenomena you so anxiously awaited to see before the eclipse are now happening in reverse. Think fast and you'll see them all again, perhaps for the last time in your life, certainly the last time for a year or more.

Watch for a repeat performance of the chromosphere, the diamond ring, followed by Baily's beads. Look for the Moon's shadow racing off into the east. As the sunlight returns examine the ground for shadow bands. Did you miss any of these phenomena at second contact? Here's a second chance to see them.

Eclipse Optics

As you can tell, there's a lot to look for during a total eclipse. What type of telescope do you need to see everything? None! You can get memorable views with just the naked eye and a pair of binoculars. They should have at least 7 or 8 power. Ten- or 16-power binoculars are better still for resolving details in the corona and seeing prominences.

Your binoculars should have an aperture of 40 to 50mm. Therefore 7x42, 7x50, 8x56, 10x50, and 16x50 binoculars are all excellent for eclipse-watching. At Hawaiian sites you should securely mount the binoculars to a tripod. It will make a world of difference, steadying the image and allowing you to see more. In Mexico, where the Sun is at the zenith, mounting binoculars on a tripod isn't practical — you can't get under them very well to look straight up. Holding them in your hands to look up if you are standing, especially for 7 minutes, will be painful on the neck and tiring on the arms. The solution? Bring a blanket or air mattress and lie down on the ground.

Binoculars are a necessity. A telescope is an optional luxury. The higher magnification and resolving power of a telescope *is* useful for glimpsing the chromosphere and prominences and for seeing small structures in the corona. If you take a telescope, take a low-power eyepiece, no more than 25x. You want a field of view at least 1° wide, enough to contain two Moon diameters (you can check the field of view before eclipse day). If the magnification is too high and the field of view too narrow, you won't see much of the broad corona. Also, if you take a telescope to Mexico, be sure it will aim straight up without hitting the tripod.

The Partial Eclipse

Even if you are staying home, you'll still be able to participate in an eclipse event. The partial eclipse may be a sideshow to the main attraction but it's still a show you won't want to miss. With the exception of those in northern New England and Alaska, observers everywhere in the United States will be able to see part of the Sun covered by the Moon on July 11. As the map on page 71 shows, the farther south and west you are the more of the Sun you'll see covered. Those north of the northern limit won't see any eclipse at all.

You'll need to use a safe solar filter for the entire event. An alternative is to use binoculars or a telescope to project the Sun's image onto a white surface. (See pages 66 and 70 for details.) It's important to take the warnings and precautions on those pages seriously. Even if 99 percent of the Sun is covered (such as on the island of Maui), the remaining 1 percent of the Sun is still dangerously bright to look at with an unprotected (or improperly protected) eye. Doing so can result in permanent eye damage. People who sustain an eye injury will at best see a negative image of the Sun superimposed on everything they see for the rest of their lives. At worst, the result can be permanent blindness.

At first contact, the Moon will touch the right-hand edge of the Sun. From North America the Moon will then move from right to left across the southern half of the Sun. As the Moon traverses the solar disk, watch for individual sunspots to be covered up. Through a telescope inspect the dark edge of the Moon closely. You might be able to see that it's jagged. The rough edge is from profiles of mountains and craters along the lunar limb. And don't forget to look for solar images projected by natural pinholes such as the spaces between leaves.

For those in the Southwest, southern California, and the northern islands of Hawaii enough of the Sun will be covered to make the day grow noticeably darker, and perhaps slightly cooler, at mid-eclipse. However, only from sites just outside the path of totality (such as Maui) will it get dark enough to feel like night is falling.

Look to the Future

The excitement generated at every eclipse always prompts a key question: When is the next one? Once bitten by the eclipse bug, people can't wait for the next opportunity to stand in the Moon's shadow. For North Americans, the year of the next total eclipse on home soil is often listed as 2017. On August 21 of that year the umbra will sweep diagonally across the United States, bringing 2 1/2 minutes of totality to sites along the path. But to be accurate, the next North

SERPENTS AND SKY-EATERS

by James Ehmann

The ancient people of Hawaii and Mexico had their own ideas about why day turned suddenly into night.

When the edge of the Moon slices into the solar disk in July, native Hawaiians who are descended from Samoans might think of Luna, a nice enough lad whose one sin was gluttony. At a typical lunch he ate 14 coconuts, 23 bowls of poi, 16 servings of roast pig, and 40 bunches of bananas.

One afternoon when he was swimming, he met the largest fish he had ever seen, the King of the Sharks. He tried to net the beast, but the fish was faster. With a great swish of his tail, the shark knocked Luna out of the sea, into the heavens. "Now you can eat the sky!" the King of the Sharks said. On July 11, Luna, the Moon, will take the only bite he cannot handle. He will sample the Sun and find it too hot for his taste.

In Mexico, the Mayan (A.D. 200 to 800) and Aztec (A.D. 1200 to 1500) civilizations had eclipse tales that tell of battles between gods vying for their rightful place in the sky. This type of legend also comes from the Toltec Indians. They celebrate Chicovaneg, the young man who sacrificed all to restore the Sun after the gods of evil had destroyed it with freezing storms. "I have a young and beautiful wife and a strong and shrewd son, an aged mother who requires my support, and at least a dozen good friends. Yet what use is all this when my people are without a Sun? All men are perishing," Chicovaneg cried.

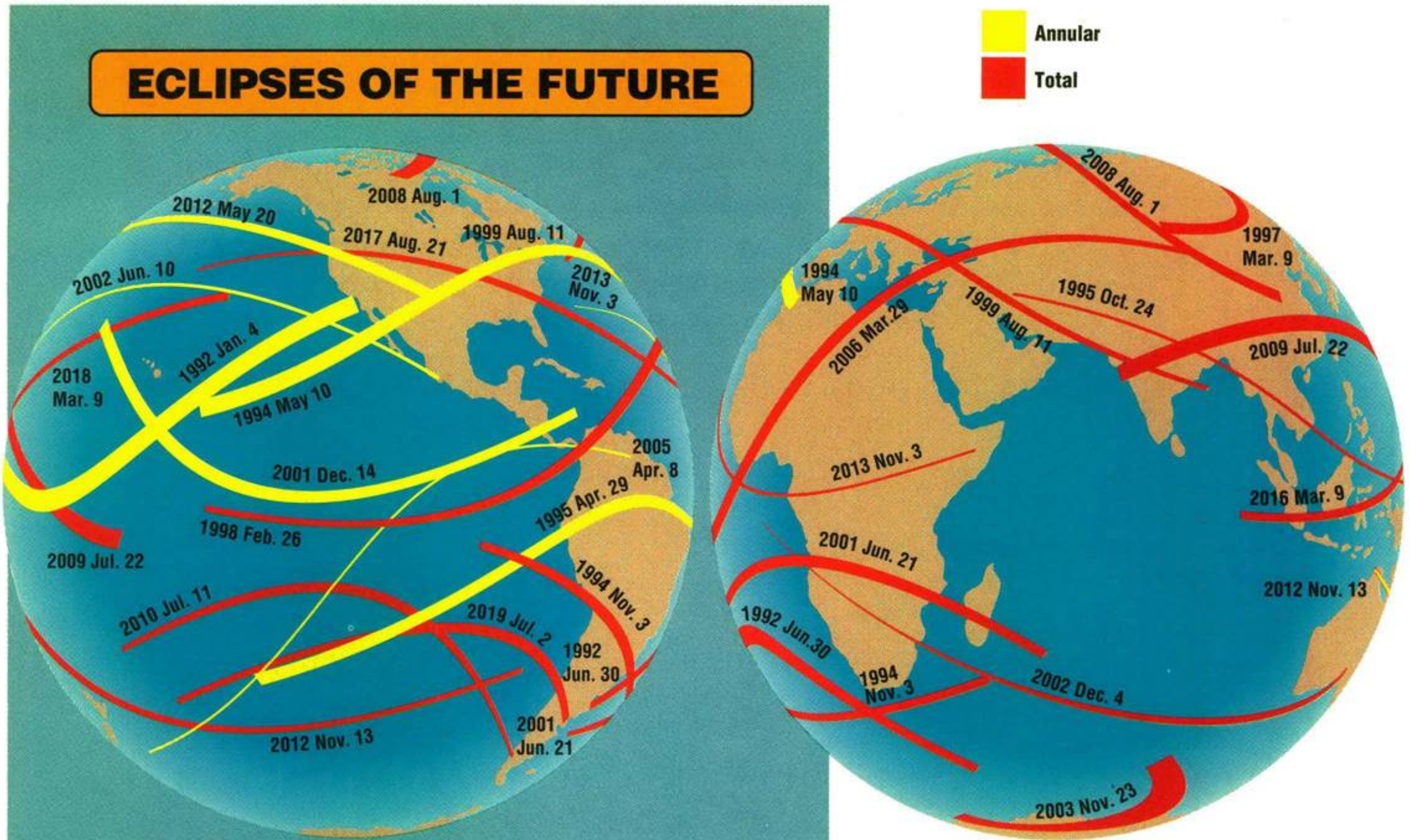
So Chicovaneg, in alliance with the Plumed Serpent, ascended to the heavens and collected light from every star to make a new Sun. To this day, serpent and man defend the new Sun against evil.

Years later, Lequilants, Chicovaneg's wife, told her son, "The people also need a Sun at night." So the son, Huachinog-Vaneg, followed in his father's footsteps and set out to create the Moon. "Should you meet your father in the sky, " Lequilants said, "tell him that I think of him always in true love."

At eclipse time, father and son reunite with delight, sharing their pride in their accomplishment and their love for Lequilants. For almost seven minutes in July, the Sun and the Moon will be lonesome no more.

James Ehmann has written for Omni *and* Reader's Digest *and is a two-time winner of the AAAS-Westinghouse Science Journalism Award.*

ECLIPSES OF THE FUTURE


🟨 Annular
🟥 Total
2008 Aug. 1
2012 May 20
2017 Aug. 21
1999 Aug. 11
2002 Jun. 10
2013 Nov. 3
1992 Jan. 4
2018 Mar. 9
1994 May 10
2005 Apr. 8
2001 Dec. 14
1995 Apr. 29
1998 Feb. 26
2009 Jul. 22
1994 Nov. 3
2010 Jul. 11
2019 Jul. 2
1992 Jun. 30
2001 Jun. 21
2012 Nov. 13
1997 Mar. 9
1994 May 10
1995 Oct. 24
2006 Mar. 29
1999 Aug. 11
2009 Jul. 22
2013 Nov. 3
2016 Mar. 9
2001 Jun. 21
2012 Nov. 13
1992 Jun. 30
1994 Nov. 3
2002 Dec. 4
2003 Nov. 23

Date	Type	Duration
1992 Jan. 4	**A**	**11m41s**
1992 Jun. 30	T	5m21s
1994 May 10	**A**	**6m13s**
1994 Nov. 3	T	4m23s
1995 Apr. 29	A	6m37s
1995 Oct. 24	T	2m09s
1997 Mar. 9	T	2m50s
1998 Feb. 26	T	4m09s
1999 Aug. 11	T	2m23s
2001 Jun. 21	T	4m56s
2001 Dec. 14	A	3m53s
2002 Jun. 10	**A**	**0m23s**
2002 Dec. 4	T	2m04s
2003 Nov. 23	T	1m57s
2005 Apr. 8	A/T	0m42s
2006 Mar. 29	T	4m07s
2008 Aug. 1	**T**	**2m27s**
2009 Jul. 22	T	6m39s
2010 Jul. 11	T	5m20s
2012 May 20	**A**	**5m46s**
2012 Nov. 13	T	4m02s
2013 Nov. 3	A/T	1m39s
2015 Mar. 20	T	2m47s
2016 Mar. 9	T	4m09s
2017 Aug. 21	**T**	**2m40s**
2019 Jul. 2	T	4m32s

T = Total A = Annular A/T = Annular/Total
Eclipses in **boldface** have paths that touch North America, though some just barely. The table and maps do not include annular eclipses in the Eastern Hemisphere or any partial-only eclipses.

THE GLOBE IS CRISSCROSSED with eclipse tracks over the next 30 years, but only a few approach North America. Tracks in red are total eclipses, tracks in yellow are annulars. Illustration by Tom Hunt based on computer graphics supplied by Andrew Lowe.

American total eclipse is August 1, 2008. At sunrise the Moon's shadow just grazes the Boothia Peninsula in the Canadian Northwest Territories before heading off across the Arctic archipelago, Greenland, and into northern Siberia.

The next total eclipse anywhere in the world is June 30, 1992. The only landfall is at sunrise near Montevideo in Uruguay, South America. The rest of the eclipse path is in the South Atlantic. Two years later followers of the Moon's shadow will return to South America for a total eclipse on November 3, 1994.

The next partial eclipse in North America is January 4, 1992. It is an annular eclipse in the Pacific Ocean but viewers along the west coast of the United States and Canada will see a partial eclipse at sunset. Southern California viewers will see the Sun set in annular eclipse, an unusual sight. On May 21, 1993, the Moon's shadow passes above the north pole, bringing a morning partial eclipse to most of Canada and the central and western United States. A year later, on May 10, 1994, an annular eclipse will sweep across North America from southwest to northeast, with several large cities (El Paso, Kansas City, St. Louis, Chicago, Detroit, Cleveland, and Toronto, among others) on or near the path. The Moon will appear much smaller than the Sun and will be within the Sun's disk for a maximum of 6 minutes and 13 seconds.

European astronomers may take exception to labeling the 1991 eclipse "the eclipse of the decade." *Their* eclipse of the decade occurs on August 11, 1999. The Moon's shadow will cross the center of Europe for the first time since 1961. Between now and then, most of the total eclipse action is in South America or, as in 1995, in Southeast Asia.

Where will you see your next eclipse? South America? Europe? Or here in North America in 2017? They all seem far in the future. Back in 1979, so did this one, and now it's about to happen.

Whether you stay on the sidelines for the partial phases, or head for the path of totality, enjoy the show on July 11. It will be a day to remember for the rest of your life. ☐

Journey to the Center of the Galaxy

Unlock the splendor of bright deep-sky objects near the galactic center with binoculars and small telescopes.

by Phil Harrington

Galaxies are richly filled with stars, gas, and dust, the glowing embers of energy that bathe the otherwise dark universe in light.

Our Galaxy, the Milky Way, contains countless star clouds and is laced by intricate networks of glowing gas in the slow process of coalescing into stars. Considered by most astronomers to be an Sb spiral galaxy (though now some believe it to be a barred spiral), the Milky Way spans some 100,000 light-years and is estimated to contain about 400 billion stars. Unfortunately our view of the real action in the Milky Way is largely obscured by thick pockets of dust. Rather than sitting near the center of the Galaxy, we are situated about 25,000 light-years out. Nevertheless, with telescopes and our minds working as spaceships of the imagination, we can observe many of the brightest objects toward the center of the Galaxy — the huge clouds of gas, dust, and stars lying in the thick of the action of our home star system.

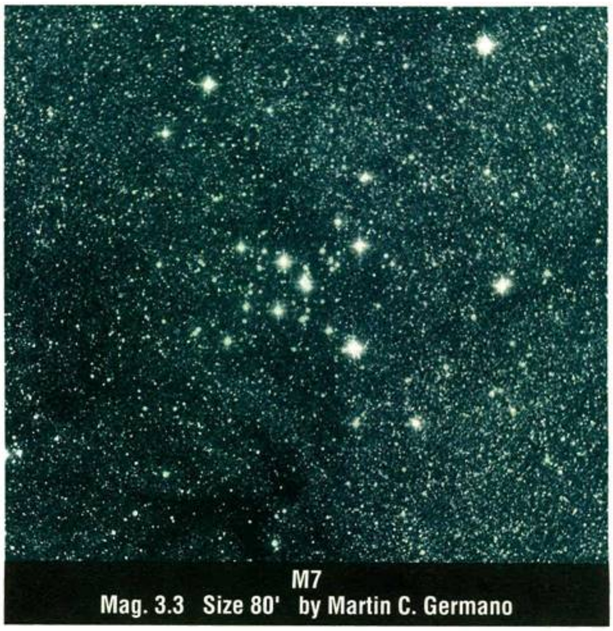
Our hunting ground will be confined to Sagittarius and Scorpius — two constellations of the zodiac that lie due south in the mid-evening hours during the summer months. Sagittarius is the Archer of mythology but to modern observers its brightest stars form an asterism that appears like a giant teapot. Scorpius, on the other hand, has bright stars that outline the general appearance of a scorpion. The actual galactic center is obscured by dust clouds, but the direction toward that point is known. It is a position on the sky 1.5° southwest of the star X Sagittarii, midway between the bright Lagoon Nebula and the star cluster M6.

Few people would argue that the most spectacular object in the region of the galactic center is the **Lagoon Nebula**, also known as M8 (NGC 6523). The Lagoon Nebula is one of the largest, brightest, and most detailed emission nebulae in the sky. Emission nebulae glow under their own power, their ionized gas excited into luminescence from the energy of young, hot stars buried within.

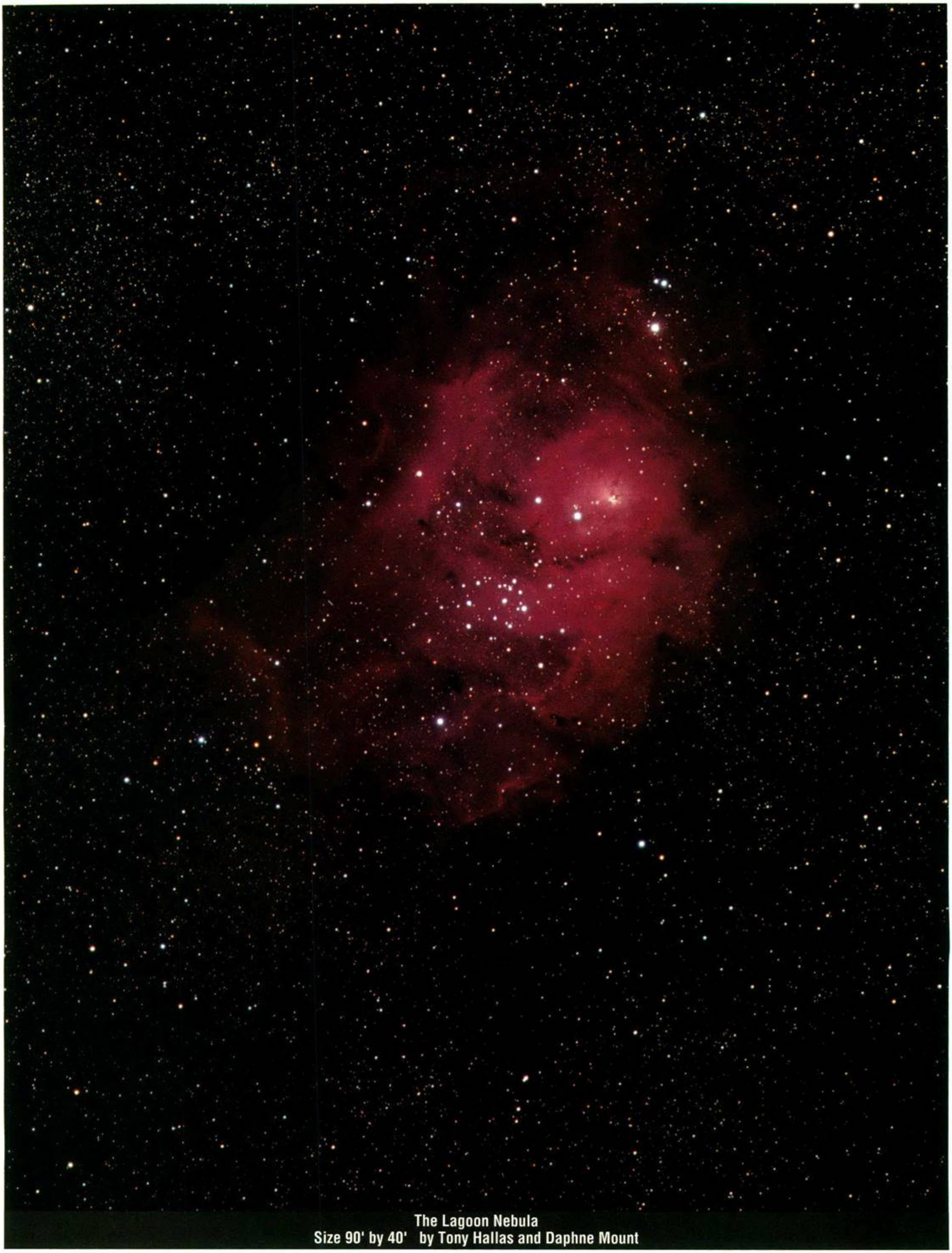
On a clear, moonless night, M8 is easily visible to the unaided eye as a bright spot in the Milky Way northwest of the teapot's "spout." A 4- to 6-inch telescope reveals a glowing cloud bisected by a dark lane, or "lagoon." Eight- to 10-inch instruments begin to disclose some of the fainter portions of the nebula, while larger telescopes show a wealth of detail.

Begin your visit to M8 by using your lowest-power, widest-field eyepiece. This way you will be

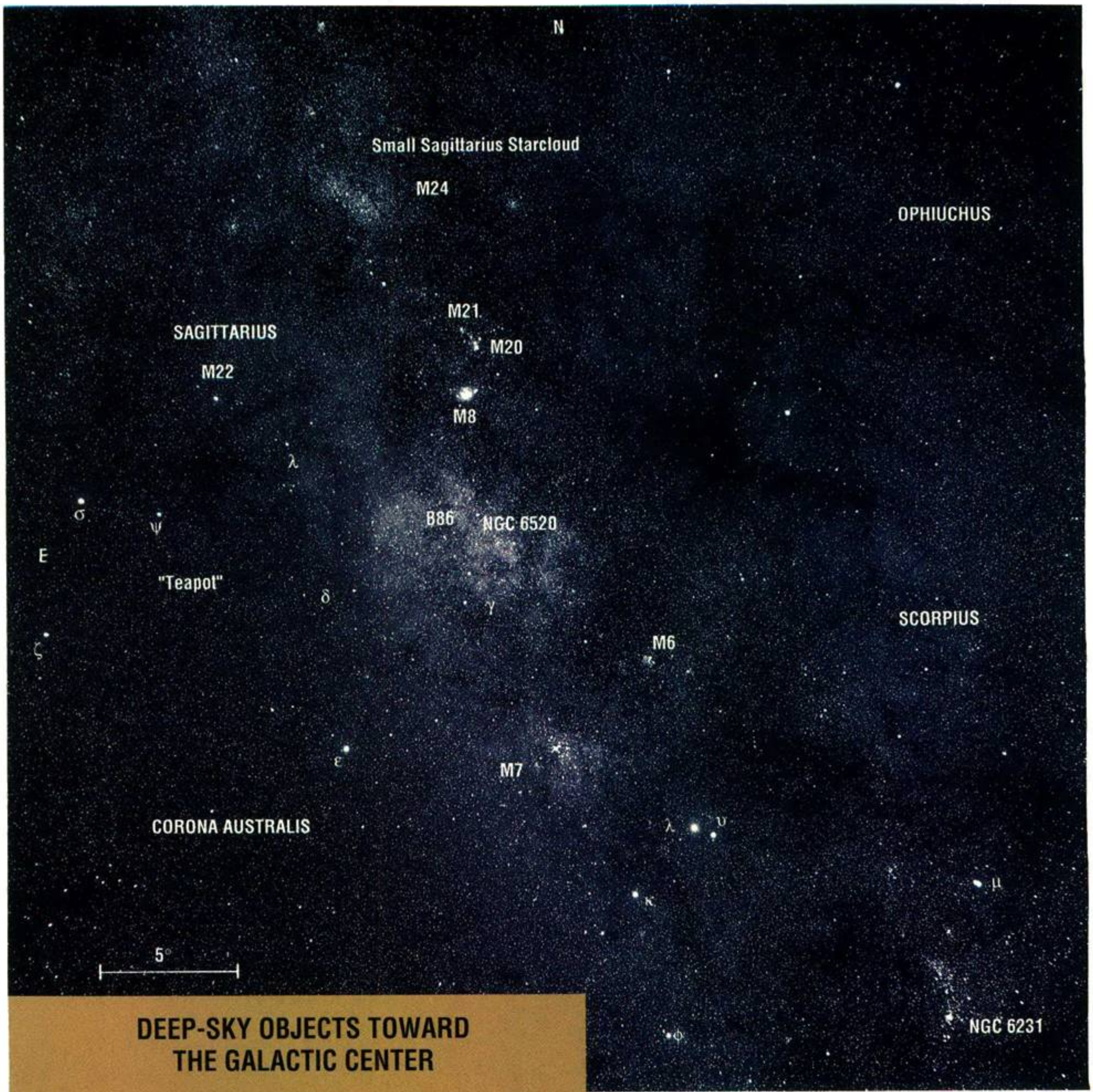
M22
Mag. 5.1 Size 24.0' by John P. Gleason



M7
Mag. 3.3 Size 80' by Martin C. Germano



The Lagoon Nebula
Size 90' by 40'   by Tony Hallas and Daphne Mount

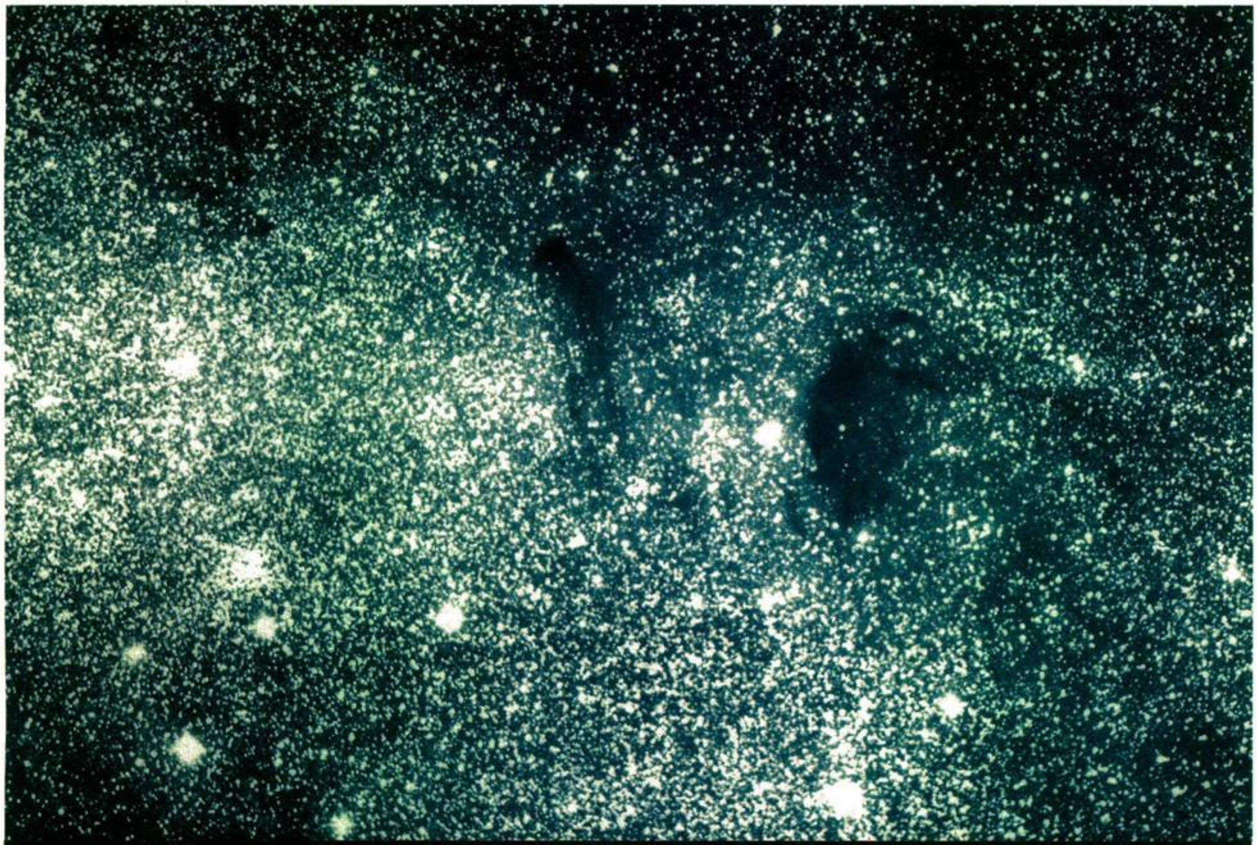

N
Small Sagittarius Starcloud
M24
OPHIUCHUS
M21
SAGITTARIUS
M20
M22
M8
λ
σ
ψ
B86
NGC 6520
E
"Teapot"
δ
γ
SCORPIUS
ζ
M6
ε
M7
CORONA AUSTRALIS
λ
υ
μ
κ
5°
φ
NGC 6231

DEEP-SKY OBJECTS TOWARD THE GALACTIC CENTER

Object	R.A. (2000.0)	Dec.	Type	Mag.	Size
NGC 6231	16h54.0m	-41°48'	OC	2.6	15'
M6 (NGC 6405)	17h40.1m	-32°13'	OC	4.2	15'
M7 (NGC 6475)	17h53.9m	-34°49'	OC	3.3	80'
M20 (NGC 6514)	18h02.6m	-23°02'	EN+RN	—	29' by 27'
B86	18h02.7m	-27°50'	DN	—	4'
NGC 6520	18h03.4m	-27°54'	OC	7.6p	6'
M8 (NGC 6523)	18h03.8m	-24°23'	EN	—	90' by 40'
M21 (NGC 6531)	18h04.6m	-22°30'	OC	5.9	13'
B92	18h15.5m	-18°11'	DN	—	12' by 6'
B93	18h16.9m	-18°04'	DN	—	12' by 2'
NGC 6603	18h18.4m	-18°25'	OC	11.1p	5'
M22 (NGC 6656)	18h36.4m	-23°54'	GC	5.1	24.0'

Object: Designation in Messier, NGC, or Barnard catalog. **R.A. and Dec.:** Right ascension and declination in equinox 2000.0. **Type:** DN = dark nebula; EN = emission nebula; GC = globular star cluster; OC = open star cluster; RN = reflection nebula. **Mag.:** V magnitude of object. Subscript p = photographic magnitude. **Size:** Diameter in arcminutes.

M24
by George Viscome



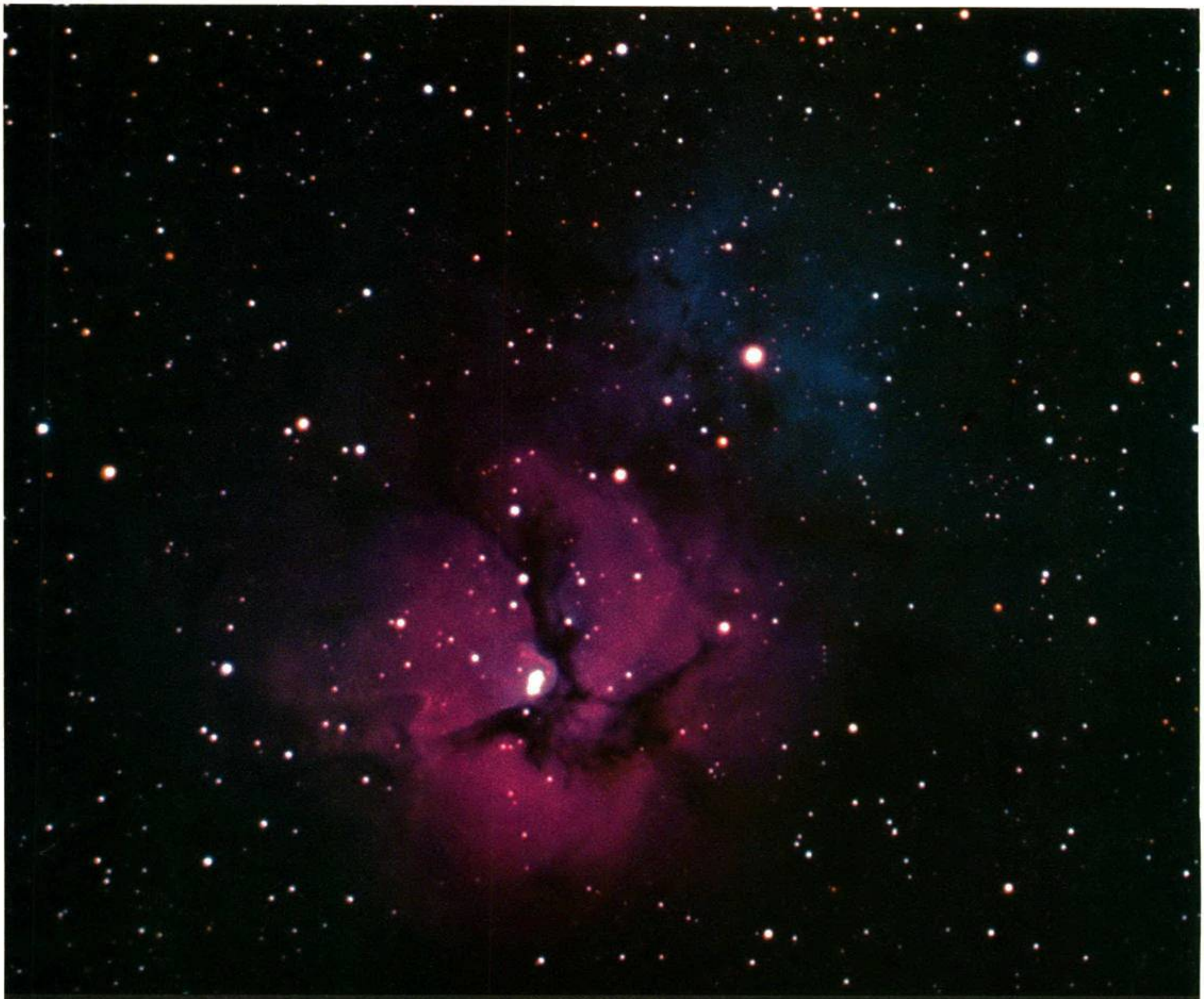
Barnard 92
Size 12' by 6' by Martin C. Germano

able to get most of its full 90' by 40' dimensions inside a single field of view. Then switch to a higher power to zoom in on areas that interest you. The Lagoon is too splendid an object to be fully appreciated with just one look — you'll see more and more in it as one summer season follows another and your eye becomes more practiced. No matter how often I look at M8, I always find something new, something I have never noticed before. One thing I'd like you to notice is the open star cluster **NGC 6530**. It is visible in the eastern part of the Lagoon Nebula. NGC 6530 consists of about two dozen stars ranging from 7th to 9th magnitude and scattered across 15'. Taken by itself, the cluster would be a fine object, but with the added beauty of M8's soft, gossamer clouds, the field is truly striking.

To me, the **The Trifid Nebula**, M20 (NGC 6514) — an emission nebula just 2° northwest of the Lagoon — looks like a celestial flower. The "petals" of the Trifid appear bright through large backyard telescopes (and a narrow-band nebula filter makes them obvious). The Trifid Nebula appears in photos as a vibrantly colored cloud trisected by dark lanes. Six-inch and larger telescopes deliver a view of M20 that approaches these photographs in detail. Through my 8-inch f/7 Newtonian reflector, the nebulosity is bright and obvious. The dark rifts first seen by 18th-century observer William Herschel are visible, first by averted vision only, then directly. Regardless of your telescope, you'll gain the best views of M20 through eyepieces yielding 100x to 150x. While you're in the area, you can take a look at a pretty, bright star cluster. Less than 1° northeast of M20 is the sparkling open cluster **M21** (NGC 6531). Binoculars and finderscopes reveal a blur of stardust speckled with a few 8th-magnitude points of light, while 6-inch telescopes display about half the cluster's 70 stars spread over 13'. Given its distance of 4,000 light-years, the cluster's true diameter must be close to 15 light-years.

After you've enjoyed looking at the Lagoon-Trifid region, set your optics aside and gaze above the teapot's spout with your eyes alone. There, along the stream of the Milky Way, you'll see two clouds of milky light. The largest (and northernmost) is the Scutum star cloud, while the other is the Small Sagittarius star cloud, also known as **M24**. This object is made up of a rich area of thousands of stars appearing to be concentrated together due to our line of sight. Therefore, M24 is best visible in low-power binoculars. From dark-sky observing sites, the splendor of this area is unparalleled in the region: a thick blanket of minute stars lies scattered throughout the eyepiece, crisscrossed by fine, dark nebulae and knots and clumps of stars. Slowly scan the cloud using a short-focus, rich-field telescope (RFT), and you'll feel as though you are floating freely among the stars.

Buried within M24 is the tiny open cluster **NGC 6603**. NGC 6603 appears as a dense group of 100 stars, none glowing brighter than 12th magnitude. Though visible in smaller telescopes, NGC 6603 demands an 8-inch instrument to be resolved into stars. After familiarizing yourself with the cloud, look closely at M24 on a dark night and you'll see two dark blotches silhouetted against the glittering backdrop of

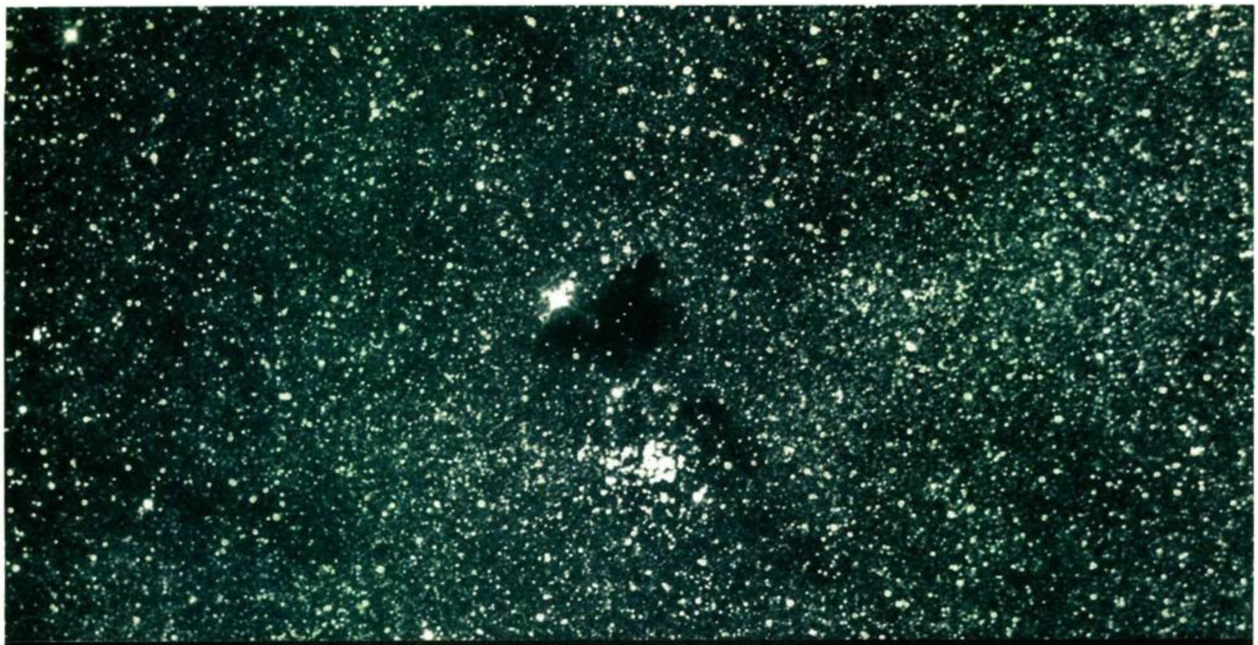


The Trifid Nebula
Size 29' by 27' by Tony Hallas and Daphne Mount

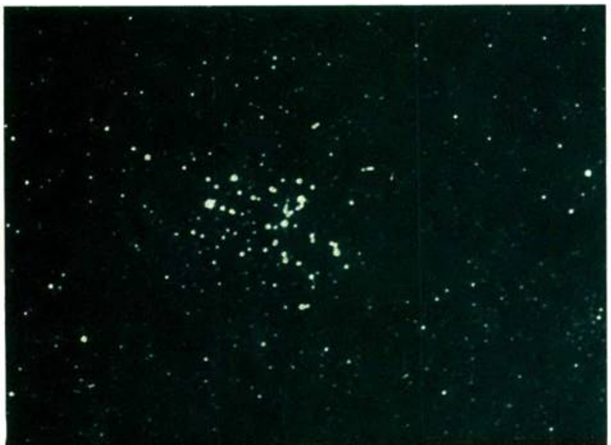
stars. This is a pair of dark nebulae — giant clouds of interstellar dust. **Barnard 92** and **Barnard 93** are visible through most telescopes as small, oval "holes" in space. Most observers spot B92 at first glance; the more subtle B93 requires some patience. Like just about all other dark nebulae, B93 is easily visible only from dark observing sites far from all sources of light pollution.

Thus far we've explored the Lagoon-Trifid region and the nearby Small Sagittarius star cloud. Now let's move south along the Milky Way to a point 4° south of the Lagoon to come upon another of Sagittarius' brightest deep-sky splendors. **NGC 6520** is a pretty open cluster set in a striking field that lies some 2° north of Gamma Sagittarii. The group consists of 60 stars, of which 20 to 25 are detectable through an 8-inch telescope. Buried in its center is a bright orange star that shines in sharp contrast against a sea of white and blue-white suns. The NGC field is even more striking because it contains the dark nebula **Barnard 86,** just northwest of NGC 6520. Remember, when you try to observe dark nebulae, it's what you *don't* see that counts. In the case of B86, you don't see any stars within a triangular wedge measuring about 4' across. Its contrast against the brilliant Milky Way star fields forces the black void to stand out even through suburban skies. Try medium power for the best view.

Now that we've surveyed the major sights of southern Sagittarius, let's move over into Scorpius. Toward the stinger of the Scorpion lies a pair of large, bright open clusters that are among the finest objects for binoculars found anywhere in the sky because of their great sizes and brightnesses. **M7** (NGC 6475) is the brighter and larger of the two. The unaided eye sees it as a misty glow about 4° northeast of Lambda Scorpii, the star marking the Scorpion's stinger. Even field glasses show M7 as a beautiful array of stars spanning 80'. Nearly a third of the 80 stars identified as cluster members are brighter than 9th magnitude and therefore visible in 7x binoculars. The brightest star of M7, a yellow type-G sun of 6th magnitude, gleams close to the group's center. Take a moment to savor its subtleties: many fainter cluster stars shine with a yellowish cast, while others appear blue-white.



NGC 6520
Mag. 7.6p Size 6' by Martin C. Germano



M6
Mag. 4.2 Size 15' by Martin C. Germano

NGC 6231
Mag. 2.6 Size 15' by Mike Mayerchek

The naked eye is all you need to detect **M6** (NGC 6405), the other bright cluster in Scorpius, as a smudge of light northwest of M7. Through binoculars, M6 appears as a dazzling open cluster of stardust surrounded by a glittering field. The first thing you may conclude about M6 is that it has an unusual boxy appearance. But when you let your imagination roam, you will see why M6 has been nicknamed the Butterfly Cluster. Do you see two stellar "wings" spreading out from the cluster's more densely packed body? The brightest of the 80 stars in M6 is an orange stellar inferno found east of the cluster's center, (in the left wing). This is **BM Scorpii**, a semi-regular variable star whose brightness fluctuates between magnitudes 6.8 and 8.7. An average of 850 days elapses between two maxima.

Now that we've surveyed the best open clusters of the region, we can move on to one of the largest, brightest, and most observed globular clusters of all — **M22** (NGC 6656). Under ideal conditions, M22 is visible to the naked eye as a hazy spot northeast of Lambda Sagittarii, the top of the teapot's lid. A 3-inch telescope resolves the cluster's brightest stars, while an 8-incher shows an uncountable number of points spanning the face of the cluster. For observers living in the Northern Hemisphere, M22 is rivalled only by the magnificent M13 in Hercules. M22 spans 140 light-years, and may hold as many as a million swarming stars. The cluster is about 10,000 light-years from Earth.

Richly glowing gaseous nebulae, scads of stars clumped into open clusters, and globe-shaped balls of thousands of stars are but a sampling of the wonders awaiting backyard observers as they look toward the center of the Galaxy. On the next clear night, take this article out with your telescope or binoculars and journey far from home toward a place bustling with stellar activity. You'll have a first-class seat on a flight of the imagination to the most thickly populated region of our Galaxy — and you'll capture "live" views of some of the Galaxy's most complex denizens. ☐

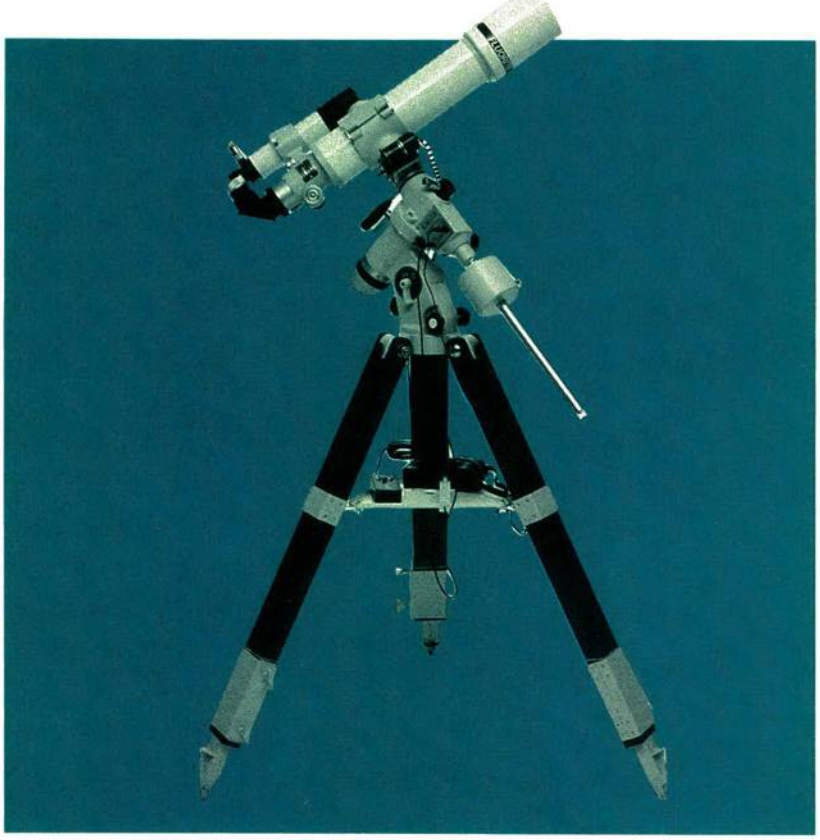
Phil Harrington is a contributing editor of Deep Sky *magazine and author of the book* Touring the Universe through Binoculars *(John Wiley & Sons, 1990).*

PRODUCT REVIEW

ASTRONOMY Tests the
Takahashi FC-76 Fluorite Refractor

From first impressions to final testing, this compact instrument proved to be the finest 3-inch telescope we've ever seen.

by Alan Dyer



Takahashi FC-76ES

Distributor: Land, Sea and Sky/Texas Nautical, 3110 S. Shepherd, Houston, TX 77098, (713) 529-3551 or 529-8480, FAX: (713) 529-3108. Also available through other selected dealers.

List Price: $2,475 with EM-1S equatorial mount, single axis DC motor drive, wood tripod, 7x50 finder, .965-inch star diagonal, 18mm orthoscopic eyepiece. Accessories tested: focal reducer for f/5.9: $294.25; vari-extender: $231; diagonal prism for 1¼-inch eyepieces: $188.95; camera angle adjuster: $136.75; electric declination motor (by Jim's Mobile): $98.50; 2-inch ocular adapter: $69.95; basic camera coupler: $32.75.

Pros: Unsurpassed optical and mechanical quality.

Cons: Complicated and expensive adapter system for visual and photographic accessories, screw-on adapters that sometimes lock tight, high cost per aperture.

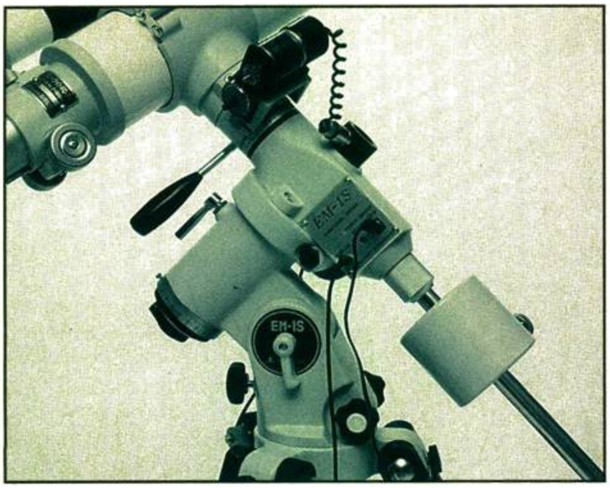
Every time a new telescope arrives at our editorial offices it's like Christmas. Yet from the moment we unpacked the Takahashi FC-76, we knew we had something special. Inside every Takahashi telescope box you find two certificates, one for the optics and one for the mount. Each is signed by the chairman of the board, Kiichiro Takahashi, as well as by the factory manager, production manager, and chief engineers, each guaranteeing the quality of the instrument now in your hands. It's an example of quality assurance all telescope manufacturers would do well to follow.

As we assembled this 3-inch refractor we soon discovered that the certificates didn't lie. The quality of all components is first rate. But at the premium price of $2,475 for the FC-76 we would expect nothing less.

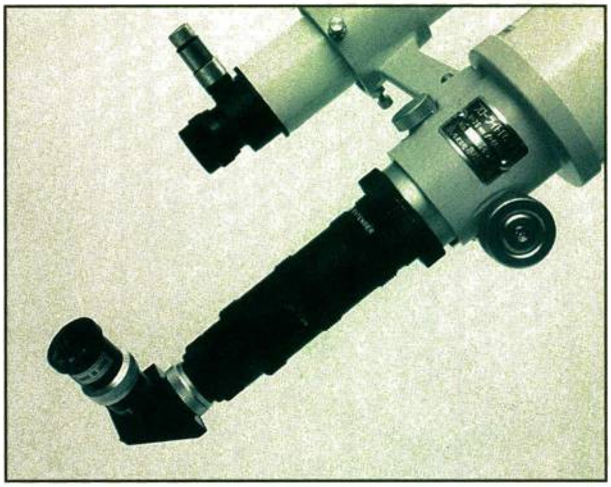
Optical Quality

Takahashi telescopes dominate the domestic market in Japan. Even in their home market, however, Takahashi instruments are high-end telescopes commanding a high-end price. Although Takahashi also makes Newtonians and a hybrid reflector called a hyperbolic astrograph, and have recently introduced Schmidt and Dall-Kirkham Cassegrain telescopes, it is their refractors that have made Takahashi famous. From their smallest 50mm model to their massive 6-inch, all are fluorite refractors — one of the elements of the front lens set is actually made of an artificially grown crystal of calcium fluorite. With its special optical properties, the fluorite element allows lens designers to virtually eliminate the traditional bugbear of refractors, chromatic aberration, a flaw that adds halos of unfocused color around bright objects. A refractor without this aberration qualifies as being "apochromatic."

That's the theory. How well does the FC-76's fluorite lens perform in practice? Very well. With images in focus, there was absolutely no chromatic aberration visible on the Moon and Jupiter, while on Venus the only color rimming the planet appeared to be atmosphere induced. When the telescope was racked out of focus, there was a mild blue coloration on bright objects inside of focus and a creamy-yellow when they were outside of focus. This was unlike some apochromatic refractors we have tested that have magenta images inside of focus and green outside. With these scopes you get the feeling that gobs of vivid color are just a touch of the focuser away.



THE SOLID CONSTRUCTION and fine adjustments of the Takahashi's EM-1S mount provided rock steady images for visual and photographic use. The mount is shown with the optional electric declination motor from Jim's Mobile.



ATTACHING ACCESSORIES to the focusing tube of the FC-76 requires a confusing system of coupling rings and extension tubes, with different combinations for visual use and photography. This set-up is for the vari-extender Barlow.

But not with the Takahashi. In addition, star tests with the FC-76 revealed textbook diffraction patterns both in and out of focus, indicating no on-axis flaws like spherical aberration and astigmatism.

By itself then, the Takahashi 76mm is impressive. But to test it further we performed a side-by-side comparison with an Astrophysics 4-inch f/8 Starfire, an apochromatic refractor whose optics use a triplet lens made of non-fluorite elements. While both scopes were wonderfully color-free in focus, the Starfire exhibited *less* color in the *out-of-focus* images. Jupiter, the Moon, Venus in a dark sky, and one of the severest tests, a mercury vapor light, all showed a touch less color than in the Takahashi when racked out of focus.

Being a 4-inch scope, the Starfire also had the brighter images of the two instruments. Nevertheless, under real-world conditions (falling night-time temperatures and less-than-perfect seeing conditions) we found that the 3-inch Takahashi provided images that showed as much planetary detail (using Jupiter as a test target) as did the Astrophysics and other 4-inch-class comparison scopes we tried. One reason is that unlike the larger telescopes, with the Takahashi there was little need to wait for the optics to cool down. The Takahashi presented sharp, contrasty planet and star images no matter what the outside temperature (and we tested this scope through a Wisconsin winter).

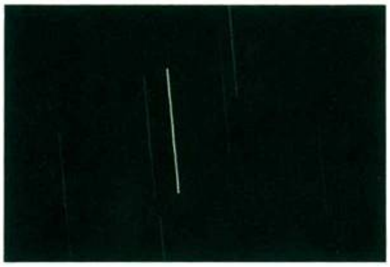
Of course, the small Takahashi, as good as it is, can't perform miracles. Although capable of delivering satisfying views of the Moon, planets, and bright deep-sky objects, it can't compete with larger telescopes for viewing faint targets and, when the seeing is excellent, the smallest planetary details.

Photographically, the FC-76 easily fills a 35mm film frame. It may seem strange to think of a 3-inch telescope as a deep-sky photographic instrument, but with its 3° field, solid mount, and aberration-free optics this is a great astrograph. In photos taken at the f/8 prime focus we did notice some mild curvature of field — stars at the corners of the frame were slightly out of focus. Using the optional f/5.9 focal reducer lens (which gives about a 4.5° field), the star images were pin sharp across the entire frame with just a trace of vignetting near the corners. Overall, on our scale of A (excellent) to E (unacceptable) the Takahashi 76mm rates an A– for optical quality.

Mechanical Quality

The Takahashi's model EM-1S mount is rock solid — making it excellent for astrophotography. One of the mount's best features is its very precise polar alignment telescope. It made it easy to polar align accurately enough that only minor tweaks in declination were required during 20- and 30-minute exposures. Polar alignment took no more than a minute.

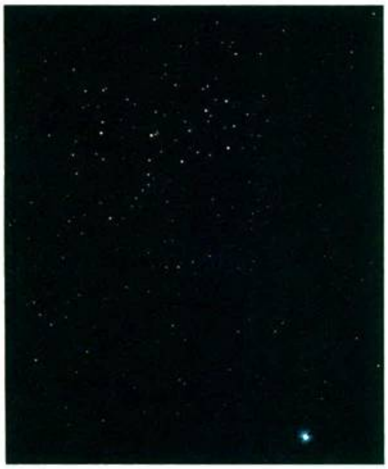
Guiding was leisurely work. Guide stars would barely move. In fact, it was possible to let the scope track unguided for 5 to 10 minutes, even shooting at the 600mm f/8 focus, and still have good star images. The manufacturer claims a periodic error of a low 13 arcseconds, a figure we confirmed. What slight tracking error there was could be corrected easily with the hand paddle. Its 2x speed correction was instant, with no backlash or overshoot. The manual declination slow motion was smooth but coarse, making it difficult to touch up small north-south drifts of guide stars without overshooting the crosshairs. Jim's Mobile Industries offers a separate electric declination motor with variable speed. We found it worked very well, but installing it requires sacrificing the manual slow motion that is useful for fast centering of objects.



OUR STANDARD TEST for drive accuracy showed very small tracking errors (wiggles in the star trails). This is a 20-minute exposure at f/8.

Even for non-astrophotographers, the Takahashi offers a host of luxury features. The 7x50 finder is one of the best we've seen. It has finely etched crosshairs that stop short of intersecting, making it easy to center targets and still see them. The crosshairs are lit by an LED whose brightness is adjustable over a useful range — under dark skies the dim setting lights up the crosshairs just enough to see them without washing out the field. On both the finder and polar alignment scopes the illuminator switches have a positive click. They are definitely on or off, unlike some of the illuminators we've seen that switch on by turning the battery

THE OPEN CLUSTER M35 was captured in a 20-minute exposure at f/8. A mild case of curvature of field throws stars at the corners slightly out of focus.



MARS NEAR THE PLEIADES last January fit the frame nicely in this 4-minute exposure at f/5.9 with the optional focal reducer.

compartment until it makes contact.

The telescope comes with a counterweight hefty enough to balance even the heaviest eyepieces, cameras, or guidescopes. The scope has six light baffles spaced down the inside of the tube to block stray light; some refractors have one or none at all. The focuser is smooth, with a touch of roughness only when the focuser is racked-in nearly all the way.

Another pleasant surprise was how long batteries lasted. The DC pulse motor is powered by four D cells but draws very little current. As a result, after three months of testing and about 150 hours of accumulated use (including being left running accidentally for a few days), the telescope kept on driving. The batteries just wouldn't quit, even on cold nights. This is in contrast to some other DC-powered drives we've used that have drawn so much power they've needed new batteries after only a few hours' use.

Flaws in the Gem

This little gem of a scope did have a few flaws. Although the Takahashi's outer glass lens is multi-coated, the inner fluorite lens did not appear to be coated at all (reflections from it were white). However, it's normal not to coat fluorite lenses since the coating process would subject the fluorite to potentially damaging heat. But this does result in about a 6 percent loss of light compared to a fully coated objective lens.

In addition, the typewritten and photocopied instruction manuals, though complete, look amateurish. Such a high-end instrument should be accompanied by higher-quality documentation.

You need the manuals, however, to figure out the telescope's very complicated and expensive adapter system for attaching eyepieces, focal reducers, cameras, and filters. Even after several months' experience with the equipment, it was still confusing figuring out what set of rings and couplers to use for a particular task. It's difficult enough sorting through the myriad adapters in the daylight; it's doubly so at night.

The accessory rings would often bind to the threads on the telescope's focuser tube. It was easy to twist a camera adapter or star diagonal a bit too far, locking it onto the scope so tightly that only brute force and big pliers would remove it. In addition, on one cold night the right ascension clutch locked tight, making it impossible to use the slow-motion control. On the EM-1S mount, loosening the drive motor clutch (and therefore disengaging the motor) is necessary to adjust the right ascension slow-motion control. This shouldn't be required. Even with a drive running, it should still be possible to override it to tweak a scope manually in right ascension to center objects.

In cold weather, turning off the polar and finderscope illuminators tended to twist the entire mechanism instead of just the rotary switch. This snapped the internal wiring in one illuminator. We were also surprised that the optional Takahashi vari-extender (a type of Barlow lens) that Land, Sea and Sky/Texas Nautical supplied with the test telescope gave slightly comatic star images. Either the lens was mounted incorrectly or was in fact defective.

Since all adapters screw on, it isn't possible with the standard camera adapter to rotate a camera independently of the tube. Framing a photo requires turning the entire tube assembly. This often put the finder at an awkward angle or caused it to hit a guidescope mounted on top. Takahashi has a solution — an accessory ring that allows you to rotate the camera smoothly while the tube stays put. It works very well. But it costs an extra $136.

The FC-76 also comes standard with a .965-inch star diagonal and eyepiece. Unlike the .965-inch eyepieces supplied with junky telescopes, Takahashi's .965-inch orthoscopic eyepieces are wonderful, with excellent eye relief and contrast. But to use your 1$^1/_4$-inch eyepieces you need yet another set of adapter rings and another star diagonal, a $189 expense.

Still, none of these flaws were major. None detracted seriously from the satisfaction of using such a finely crafted telescope. The FC-76 and the other Takahashi products we've seen set a standard few manufacturers, foreign or domestic, can meet, let alone surpass. But at $2,475 this is the most expensive 3-inch telescope on the market. And $2,475 is just the start. The required accessories will add up quickly to several hundred dollars more. But if you want the best compact telescope we've seen yet, this is it. Critics will say, "But this is only a 3-inch telescope." Sure, and a Porsche 911 is only a 2-seat car. □

ASTROPHOTOGRAPHY ON A BUDGET

Scanning the pages of any astronomy magazine or telescope dealer's catalog is a scary experience. A new hobbyist interested in, say, astrophotography, might get the impression that a substantial investment lies well ahead of the first photo ever to be produced in the darkroom. Besides the basics — camera, film, tripod — the hobbyist could pick up a strong insinuation from ads that he or she needs a retinue of filters, trackers, illuminated eyepieces, antivibration footpads, focal reducers, teleextenders, adapters, diagonals, flashlights, and dew removers. How is the novice ever going to get into astrophotography?

Several months ago beginning astrophotographer Mike Lynch of Frankfort, Kentucky, reached that point. "I asked myself that question for some time," says Lynch. "Can I take pictures like the ones in the magazines on a limited budget? I decided to find out the answer by experimentation."

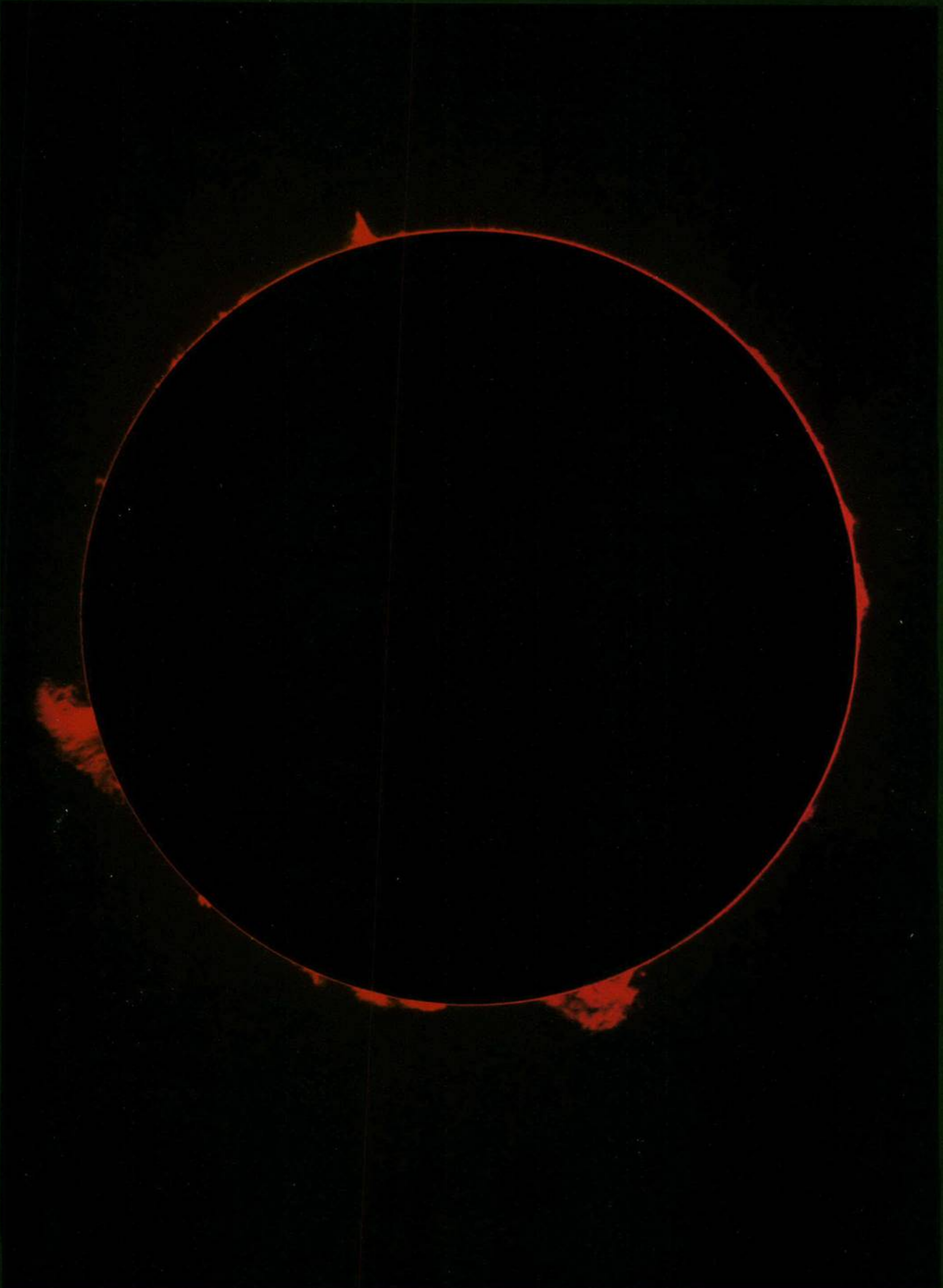
Lynch decided to avoid the high-cost, high-tech approach and aim for practicality, efficiency, and low cost. "The first thing I did was to find plans for building one of the inexpensive "barn-door" type guiding platforms. For a few bucks you can buy a little lumber, some hardware, and a 1 rpm motor and construct a platform that allows you to track stars easily. It's much cheaper and just as effective as one of the commercially available camera guiders."

Another concern of Lynch's was the fact that his observing site isn't perfect. "After seeing the photos in ASTRONOMY for several months, I came to believe that you needed perfect sky conditions to make astrophotos that were any good," remarks Lynch. "That's not true, however. Many of my original photos had green-tinted backgrounds due to light pollution, but I had the local processor remove that tint to achieve a nice, weak violet hue. By working with a local processor, you can achieve some pretty spectacular results.

THE STARS OF ORION are captured in just a 4-minute exposure made with a 30mm lens piggybacked on a telescope. Simple astrophotography can produce elegant results. Photo by Mike Lynch.

In addition, my equipment is standard, off-the-shelf stuff from the local photo store. It consists of a Pentax K-1000 camera and a 30-70mm zoom lens. The films I use are strictly unhypered, off-the-shelf rolls of absolutely ordinary types. Now that I've gotten some pretty good results, I'm through simply admiring other people's photos — I'm going to be out there taking my own!" — *David J. Eicher*

A METEOR BURSTS in a flash of light in a 25-minute exposure made with a stationary camera-on-tripod. Photo by Bill Hood.



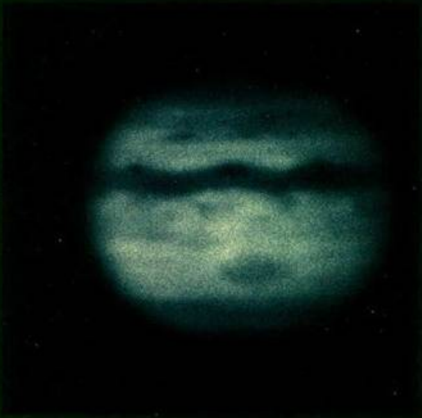
THE ACTIVE SUN

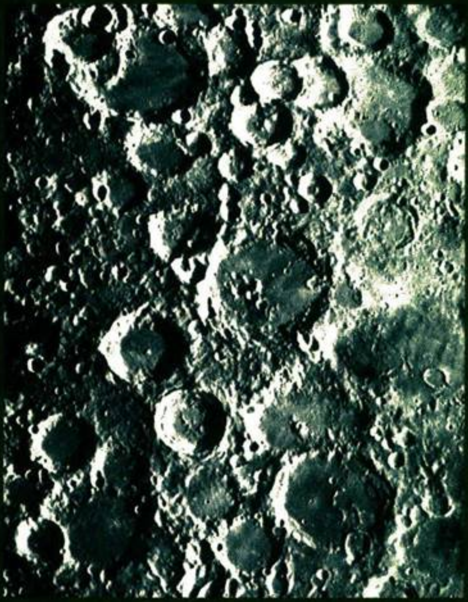
A solar disk surrounded by active prominences awaited the camera of Franz Klauser on February 17, 1990. On that day the Austrian astrophotographer recorded the Sun's disk with an 80mm f/11 Vixen refractor with a Baader 8 Å H-alpha prominence viewer. Klauser's photo (opposite page) nets this month's $100 "Best Astrophoto" award.

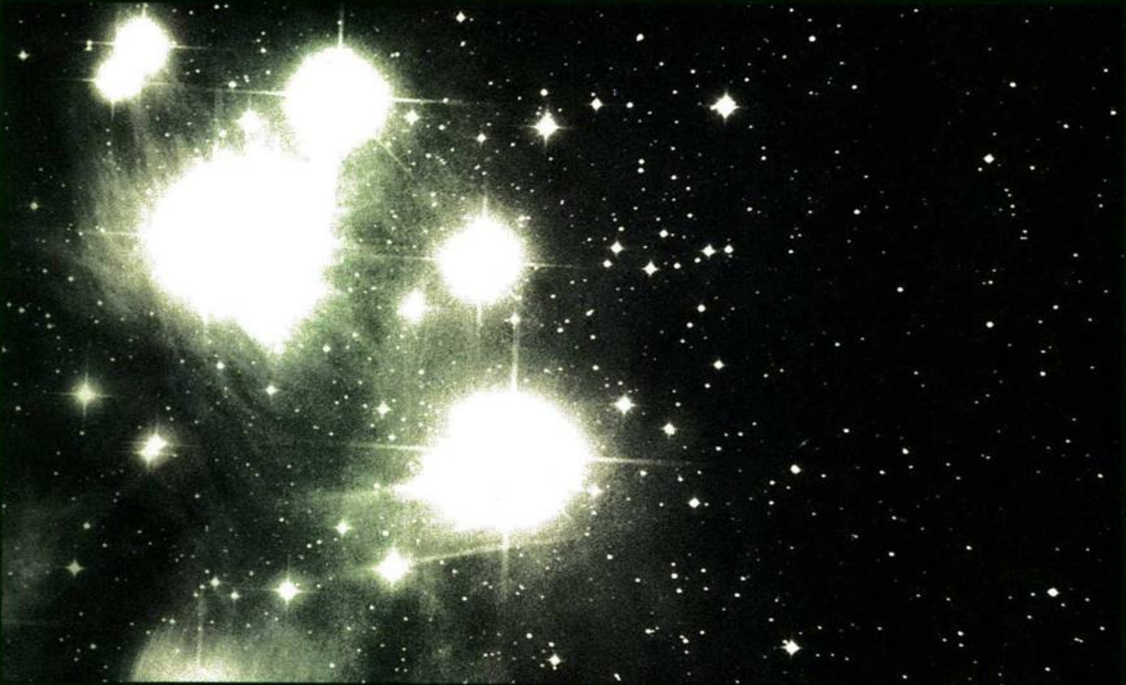
Similar solar activity sparked a magnificent auroral display on March 9, 1991. Larry Landolfi captured the aurora at the height of its activity from Long Island, New York (left). Superb crater details, rilles, and ridges characterize Christian Arsidi's photo of the lunar highlands (below).

Arsidi's fellow countryman Gerard Therin captured spectacular detail in the cloud tops of Jupiter during January 1991. Therin's January 18 image (below left) shows the Great Red Spot and large dark knots in the Northern Equatorial Belt.

Of the hundreds of reader submissions over the past month, one struck us as particularly innovative. Michael Stecker of Los Angeles took a deep exposure of the Pleiades star cluster in Taurus (bottom) — so deep, in fact, that it shows the faint galaxy UGC 2838 in the distant background (near center). Stecker used an 8-inch f/4 reflector, hypered Tech Pan film, and a 60-minute exposure to capture the faint galaxy.







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This Meade MTS-SN6 offers a superb 6 inch 750mm F/5 optical tube. It features **MCOG** multi-coated optics #788 motor drive, 1¼/2" focuser, 25mm eyepiece & sturdy MTS equatorial mount with pier.
Meade List Price
Focus Camera Sale Price **$599**

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40mm 2 inch	**253.50**		

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4.7mm 1¼"	**122.95**	6.7mm 1¼"	**147.95**
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- Celstron's latest model heavy duty adjustable field tripod (this is usually an additional cost option)
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FOCUS CAMERA'S PRICE **$1199**

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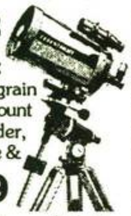

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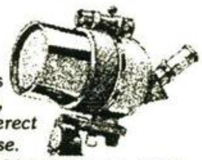

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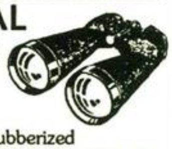

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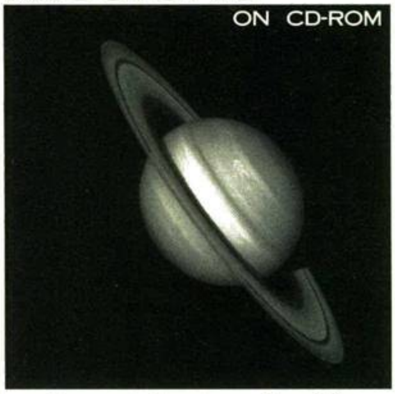

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Product Reviews

TELE VUE'S BIG BARLOW

2x Big Barlow, *Tele Vue Optics, Inc., 20 Dexter Plaza, Pearl River, NY 10965, (914) 735-4044. $295.*

For many observers, Barlow lenses are essential accessories. They double or triple the power of any eyepiece they are used with. They also have the advantage of increasing magnification, but without decreasing an eyepiece's eye relief. Eye relief is the distance from the outside lens of the eyepiece to the spot where you need to place your eye in order to look through the eyepiece. On most high-power eyepieces (4mm to 7mm focal lengths) the eye relief can be uncomfortably short, making it difficult to view through such an eyepiece. With a Barlow, however, you can use a medium-power eyepiece (such as a 12mm focal length model) that has an inherently longer eye relief and still get the high magnification you need for lunar, planetary, and double star viewing.

For those with short-focal length telescopes, achieving high power (upwards of 200x) without some sort of Barlow is next to impossible. For example, on Tele Vue's Genesis telescope with its 500mm focal length, even a 5mm eyepiece will yield only 100x. But with a 2x Barlow you get 200x.

On the down side is the poor images that some Barlows provide: added color, ghost reflections, and fuzzy images from poor optics. But the best-made Barlows on the market don't add or subtract anything from the image; they simply magnify it. We were pleased to see that Tele Vue's premium "Big Barlow" was such a unit. Its optical quality proved to be first-rate. It doubled the power but, like an optically perfect window, never gave any other indication that it was in the light path.

With the Big Barlow in place, star images — even at the highest powers (using a 4.8mm Nagler eyepiece on a 4-inch apochromatic refractor) — showed perfect diffraction patterns. Compared to the view without the Big Barlow, there was no change in the appearance of the in-focus and out-of-focus patterns when the Barlow was in place. In focus, the Airy disk and surrounding diffraction rings were perfect, with no sign of astigmatism or coma, common traits of poorly made or poorly assembled Barlows we have seen. On brilliant Venus, a severe test, the Big Barlow did not add any noticeable color or ghosting.

Tele Vue
BIG
Barlow

DESIGNED FOR TWO-INCH EYEPIECES, Tele Vue's new Big Barlow can also accommodate $1\frac{1}{4}$-inch eyepieces using the supplied adapter ring.

We did find that the Big Barlow required racking-in the focuser to refocus. We tried it with a selection of Tele Vue eyepieces (though the Big Barlow will work with any brand of eyepiece). On our 4-inch f/8 test telescope, the shift in focus varied from a maximum of 35mm with a 9mm Nagler eyepiece to a minimum of 18mm with the 40mm Wide Field and 20mm and 4.8mm Naglers. (With the $1\frac{1}{4}$-inch eyepieces we used the adapter supplied with the Big Barlow that lowers the eyepiece into the Barlow tube by about 5mm.) On refractors with lots of focus travel this difference in focus shouldn't present a problem.

When we tried the Big Barlow on an Obsession 20 telescope with its low-profile focuser, we also found that all eyepieces still focused. (With this scope the Big Barlow required that the focuser be racked in about 5mm with most eyepieces.) But when we passed the Big Barlow around at a recent star party we found some owners of homemade Newtonian telescopes were not able to use it — the scopes' focusers could not rack in far enough to refocus.

Another caveat is the added weight. Although it weighs only 8.2 ounces, combined with a heavy 2-inch eyepiece, this extra weight could cause balance problems.

Of course, the Big Barlow's advantage over standard $1\frac{1}{4}$-inch models, including Tele Vue's own 1.8x and 2.5x models, is that it can take large diameter 2-inch eyepieces. This immediately raises the question, When do you use a 2-inch Barlow? Most medium- to short-focal length eyepieces have $1\frac{1}{4}$-inch diameter barrels. In most cases, with the exception of models like the 9mm Nagler and 8.8mm Meade Ultra-Wide, only long-focal length, low-power eyepieces use 2-inch barrels. The low-power models are not the eyepieces you usually want to boost in power.

But a 2-inch Barlow does have its applications. On fast telescopes, all eyepieces, especially low-power wide-angle models, will exhibit edge-of-field aberrations. With a Barlow in place, the light cone entering the eyepiece is not as steeply angled, making it easier for any eyepiece to provide clean star images across the entire field. For example, with a 40mm Tele Vue Wide Field eyepiece on our test telescope, we found that star images at the edge of the field were tighter, with less astigmatism. A 20mm Nagler showed a similar improvement. Of course, what you gain in clean star images you lose in field of view, the very thing you may be seeking in a fast telescope with a low-power eyepiece.

A 2-inch Barlow is also handy for photography with telescopes that have 2-inch focusers and camera adapters. The Barlow will increase the effective focal length, which can be useful for lunar photography.

However, we have to conclude that although a Barlow can be very useful, a *2-inch* Barlow, even one as good as Tele Vue's Big Barlow, is a luxury item. But if you want a Barlow that will provide outstanding optical performance with *all* your eyepieces, the Tele Vue Big Barlow will do the job very well. — *Alan Dyer*

NEW SOFTWARE RECEIVED

Skyclock™ 1.0, *Skyclock Company, Box 401, Milford, MI 48381, (313) 685-8926. $64.95 (Michigan residents add 4% sales tax). For Macintosh computers.*

Skyclock presents a graphic display of the length of the day, night, and twilight, and the time of sunrise and sunset for your home location or for one of over 400 cities contained in its database. It has information on each city's latitude and longitude, on the phone codes used to reach that city (either area code or international country code), and on the airport codes for airports serving that city, as well as the offset from universal time for that city's time zone. Users can also enter new locations and can select from either civil, nautical, or astronomical twilight. Skyclock will also display the time of sunrise and sunset and length of twilight in text format. The program will run in color on color Macintosh monitors. Skyclock comes with a 50-page manual.

The Sky 4.1, *Software Bisque, 912 12th Street, Golden, CO 80401, (303) 278-4478, FAX: (303) 279-1180. Level I: $75, Level II: $99, Level III: $175. Upgrades: $35, $45, and $100, respectively. For IBM-PC and compatible computers with hard disk and minimum 640K RAM. Supports CGA, EGA, and VGA graphics.*

The latest version of this sky-charting program features improved printing of high-resolution star charts with laser and dot matrix printers. The Sky can display fields of 180° down to 0.2° across. More objects appear as you zoom in. Three versions are available: Level I has a database of 3,500 deep-sky objects and 7,500 stars. Level II features the full NGC list of 7,840 deep-sky objects with 39,000 stars. Level III offers 13,300 deep-sky objects and 259,000 stars. The three levels require 1.3, 2.8, and 9.5 megabytes of hard disk storage space respectively.

The Sky will animate the motions of the Sun, Moon, and planets and display the phase of the Moon and positions of Jupiter's moons. The user can identify objects by pointing at the object (The Sky supports the use of a mouse and pull-down menus) and search for objects by name or catalog number. Users can also create observer's logs. With optional encoders and serial interface available from Jim's Mobile Industries, The Sky can also connect to a telescope to show where the telescope is pointed and how it should be moved to find new objects. ☐

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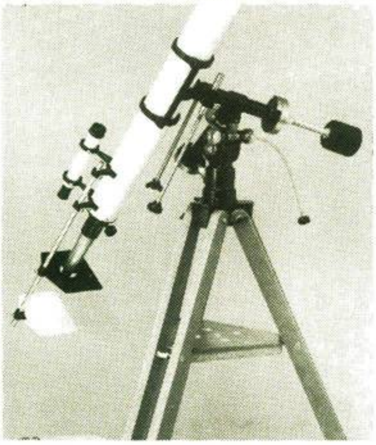

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ANNOUNCEMENT — The Ancient City Astronomy Club, Inc. meets every first Friday of the month at 8 p.m. in the First United Methodist Church, King Street, in St. Augustine, Florida. Write to P.O. Box 546, St. Augustine, FL 32085-0546 or phone (904) 797-5704 or (904) 471-3054.

ANNOUNCEMENT — The Amateur Astronomers Association of Princeton, Inc. meets the second Tuesday of each month, except July and August, at Princeton University's Payton Hall, Ivy Lane, Princeton, NJ. For more information contact Membership Chairman Greg Mauro at (609) 585-9465.

ANNOUNCEMENT — The Astronomical Society of the Palm Beaches meets the first Wednesday of each month, 7:30 p.m., South Florida Science Museum, 4801 Dreher Trail, West Palm Beach, FL 33405. Two star parties a month. Call (407) 746-8064 for information.

ANNOUNCEMENT — The Small Scope Observers Association is looking for members. If you have a scope 8 inches or smaller, drop us a line and find out more. Send your SASE to the SSOA at 4 Kingfisher Ln., Audubon Park, NJ 08106.

ANNOUNCEMENT — Space Science teachers in North Carolina announce the formation of N.C.-Astro, an organization of astronomy teachers in North Carolina dedicated to improving the teaching of astronomy in the schools of the state. It will strive to provide hands-on ideas to make space education more interesting. It will offer training opportunities during conferences and other meetings and seek to make the public more aware of the importance of astronomy. Anyone interested should write John C. Boling, Jr., Planetarium Teacher, Charlotte-Mecklenburg Schools, Charlotte Nature Museum, 1658 Sterling Road, Charlotte, NC 28209.

ANNOUNCEMENT — The newly formed Astronomical Society of Lenawee County meets at Robinson Planetarium, Peelle Hall, Adrian College, Adrian, MI. Meeting dates work around the planetarium schedule. For information call Jim Whitehouse at (517) 448-8995 or (517) 448-7173, or Joe Noffsinger at (517) 265-5161.

ANNOUNCEMENT — The Comox Valley Astronomy Club was formed in 1990. Based on mid-eastern Vancouver Island in British Columbia, Canada, it serves the area surrounding the towns of Courtenay, Comox, and Cumberland. Amateurs visiting this region are welcome to call David Graham at (604) 339-5738, or Ed Majden at (604) 338-5774. Direct Club correspondence c/o Keith Finnie, 1467 Balmoral Ave., Comox B.C., Canada, V9N 7N9.

FOR SALE — Tele Vue 32mm wide field eyepiece. Includes built-in rubber eye guard. Excellent condition. $175 firm. Phone (212) 543-2079.

FOR SALE — Meade SC 2080 LX3 8" Series 4000 Super Plossl eyepiece; colored glass filters, astro books, $1,400 all like new! For photo or info call (317) 271-1516 evenings/weekends, leave message at (317) 745-7847, or write Lon Allen, 230 Shiloh Creek Way, Indianapolis, IN 46234.

FOR SALE — Coulter 17 1/2" telescope, 2" focuser, 8x50 finderscope, $1,000. (918) 436-2204.

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New Astronomy Products

1

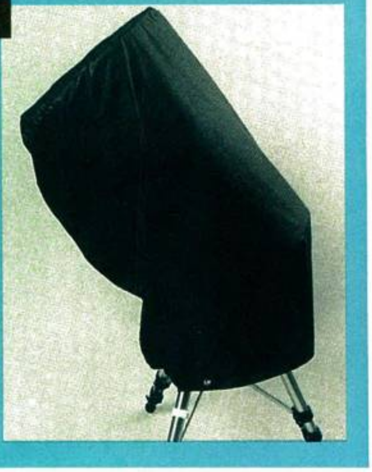
Deep-Sky Slide Set from ASP

A set of 15 color slides of nebulae and galaxies photographed with the Anglo-Australian Telescope is now available from the nonprofit Astronomical Society of the Pacific. The individual slides are produced directly from masters provided by the photographer, David Malin. The slides are accompanied by a reading list, booklet of detailed captions, and an introduction by Malin about the photographic techniques he uses.

Malin Slide Orders, Astronomical Society of the Pacific, 390 Ashton Avenue, San Francisco, CA 94112, (415) 337-1100. $23.95 (includes postage and handling). California residents add sales tax. Outside U.S. please add $3 and remit in U.S. funds.

Telescope Covers

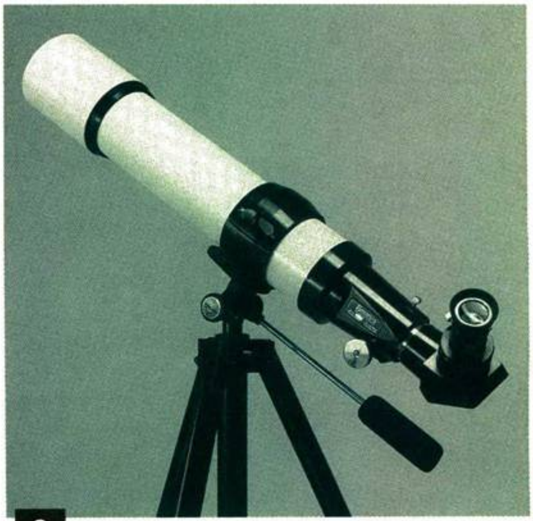
3



A new line of protective rain/dust covers for telescopes and binoculars is available from Valley Covers. Covers are available in a choice of water-repellent breathable vinyl or treated water-repellent cotton canvas. Grommet holes are included for tie-down purposes. Stock colors are blue, black, or gray. Other colors are available. Write for information on sizes and prices.

Valley Covers, P.O. Box 27144-0144, Minneapolis, MN 55427-0144, (612) 377-4636.

This department presents new product announcements issued by their manufacturers. The product information is as supplied by the manufacturers or distributors. All prices are suggested retail. Suppliers are invited to send their product announcements to the attention of Alan Dyer.

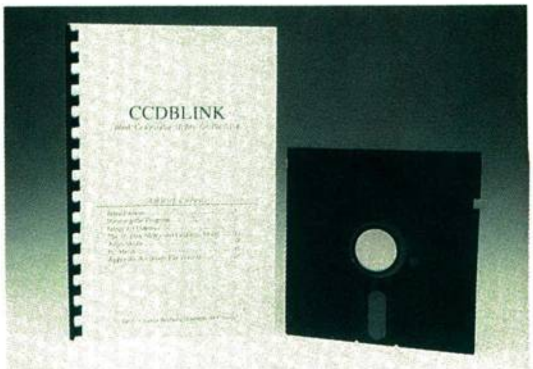


2

Tele-Pod

This lightweight tripod is suitable for cameras or portable telescopes such as Tele Vue's Genesis. Tele-Pod's spring-loaded "uni-lock" head features a single handle control for both altitude and azimuth movement and locking. A quick-release adapter screws into the camera or Tele Vue telescope mount ring to facilitate quick attachment and removal. Anodized aluminum legs extend from 28 to 47 inches with the center column extension adding an additional 18 inches of height. Rubber foot pads are retractable exposing spikes for field use. The tripod also includes a removable triangular tray. The entire Tele-Pod weighs 5 pounds.

Tele Vue Optics, Inc., 20 Dexter Plaza, Pearl River, NY 10965, (914) 735-4044, FAX: (914) 735-4112. $260.



4

CCDBLINK

This new software package allows you to load two image files, align them with sub-pixel accuracy, and then blink the display between the two images. This facilitates searching for objects that have changed position or brightness. CCDBLINK uses image files captured and saved by the Santa Barbara Instrument Group ST-4 camera and software.

Santa Barbara Instrument Group, 1482 East Valley Road, Suite #J601, Santa Barbara, CA 93108, (805) 969-1851, FAX: (805) 969-0299. $129.

5

Equatorial Mount Kit

University Optics is now offering a German equatorial mount in a fully machined ready-to-assemble kit form. All components are heavy sand-cast aluminum. Shaft size is 1.5-inch with Oilite thrust bearings. The head is designed to fit on top of a 4-inch pipe. The mount assembles in five minutes and will carry reflectors up to 10-inch f/6 and refractors up to 6-inch f/10.

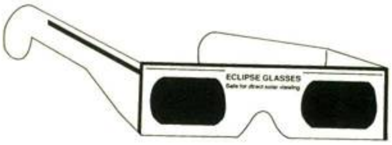
University Optics, P.O. Box 1205, Ann Arbor, MI 48106, (800) 521-2828 or (313) 665-3575. Introductory price: $395.95, f.o.b. Ann Arbor, Michigan.

6

Eclipse Glasses

These glasses use aluminized Mylar from Thousand Oaks Optical, a filter material proven safe for direct solar and eclipse viewing. The material is mounted in a cardboard frame labeled with instructions and safety warnings. Quantity discounts are available to telescope dealers, planetariums, science centers, and astronomy clubs. Glasses also come with an educational safety booklet. Call for quantity prices.

ABELexpress — Custom Products Division, 230-N East Main Street, Carnegie, PA 15106, (800) 542-9001. $1.00 each, plus flat $1.00 shipping and handling for any quantity in the U.S. Contact company for information on foreign orders.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7

Optolyth Roof-Prism Binoculars

Optolyth USA has announced the availability in the United States and Canada of the German-made Optolyth Royal Series of high-power roof-prism binoculars. All feature rubber armoring, high eye relief suitable for use with eyeglasses, and Ceralin® Plus coatings for high light transmission and contrast. All models come with a hard leather storage case. The 12x63 also has a built-in tripod adapter.

Optolyth USA, 18805 N.E. Melvista Lane, Hillsboro, OR 97123, (800) 447-6881 or (503) 628-0246, FAX: (503) 628-0797. Royal Series 7x50: $1,300, 8x56: $1,230, 9x63: $1,435, 12x63: $1,500. □

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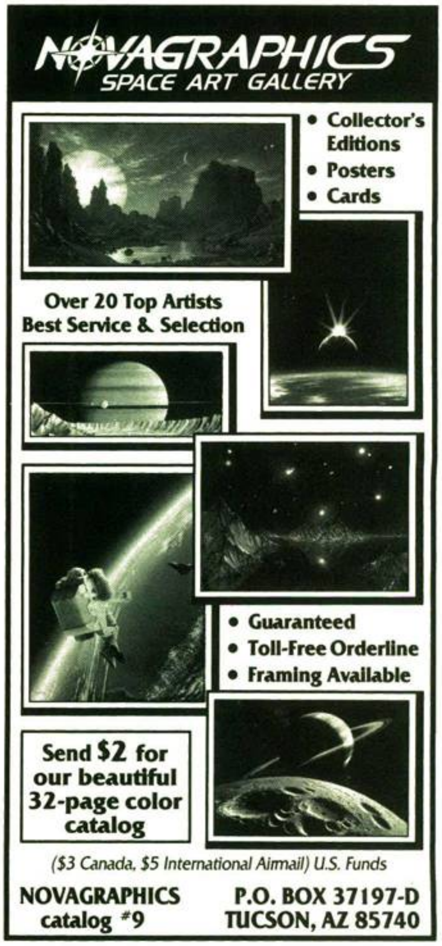
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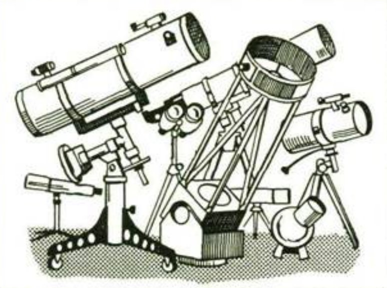

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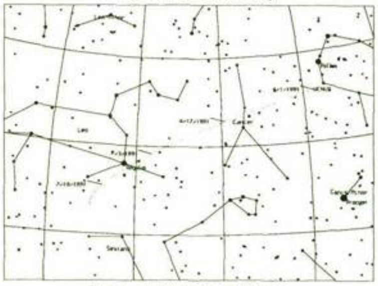

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A GREAT BOOK ABOUT WHERE IT'S ALL GOING

Lonely Hearts of the Cosmos, by Dennis Overbye, (Harper Collins, 1991), ISBN 0-06-015964-2), 438 pages, hardcover, $25.00.

Forget the cornball title. This is a very interesting book about the people and theories of cosmology — the astronomical science of where it's all coming from and where it's all going. *Lonely Hearts* manages to hit a highly enjoyable balance between the human side of this pursuit and good descriptions of the scientific results.

But the book is not for the timid. Overbye demands your full attention as he guides you through a labyrinth of modern physics, pausing at the personalities and rivalries that greatly enrich the story.

The book opens with a 1954 scene of a young man wearing a bomber-pilot jacket and a grin on his face. This is Allan Sandage in his late 20s, already a major player in the pursuit of answers to the ultimate question. Then and now, Sandage is one of a handful of humans with access to the 200-inch telescope at Palomar, the instrument that provides answers to those ultimate questions. Although *Lonely Hearts* is told largely through interviews with Sandage, it also explores in detail the accomplishments and contributions of many other scientists.

In a real sense today's cosmology actually began with Edwin Hubble, who in 1929 announced the discovery of the expanding universe. As a graduate student Sandage found himself in Hubble's footsteps and continued and greatly furthered the work after Hubble died in 1953. Their work showed that cosmology, the study of the age and structure of the universe, was indeed an observational science — an idea that didn't meet with total acceptance from every astronomer during the early decades of this century. Today almost all cosmological research descends from the work of Hubble and Sandage — although at times it has gone in directions that Sandage doesn't agree with.

Other scientific personalities also loom large in the book. There is Stephen Hawking, a brilliant British physicist whose recent book *A Brief History of Time* was a bestseller. Hawking is one of the purveyors of ideas about black holes, the cosmic singularities that have literally dropped out of sight but still dominate the space around them. There is also David Schramm, an astrophysicist who sees the universe as "the poor man's particle accelerator," and Beatrice Tinsley, who estimated that there wasn't enough mass in the universe to reverse the expansion discovered by Hubble.

The book runs heavy on descriptive physics, which is something I like, but which may be troublesome for other readers. The author covers the crucial subjects in extraordinary detail, writing in non-technical prose and avoiding that scientific mainstay, charts and diagrams. This omission might endear the author to the general lay reader, but those who have even slight knowledge of the subject will feel somewhat cheated. The words are here, but the points could be made more forceful with just a few graphs. For example, the first one published by Hubble that suggested expansion of the universe would make a great impression on any reader.

In any case Dennis Overbye does an amazingly good job of describing such arcane concepts as inflation theory and the resolution of the flatness problem. He interviewed the originators of the grand unified theories in particle physics and of the pancake theory to account for the distribution of galaxies. He describes the importance of large voids in space and the evidence for dark matter surrounding galaxies. The latter leads directly to the question: Do we have a complete understanding of the basic laws of physics?

My interest flagged in only a few places. For example, at one point Overbye pursues Hawking about the possibility of parallel universes. Hawking was either uninterested in the subject or was annoyed at his interviewer. The result is that this one section just doesn't take off.

The book ends with a cosmology conference set at a Hawaiian resort. Bikini-clad beauties stop to look in at a half-darkened room with a solitary projector screen, then quickly leave.

In the darkness a showdown is taking place between Sandage and Gérard de Vaucouleurs, a French-born cosmologist with new ideas about distances to the galaxies. The controversy centers on the expansion rate of the universe. If the rate is slow, the universe will collapse; if the rate is fast, the universe will expand forever. The conference organizer has filled the meeting with Sandage's scientific opponents. Sandage expects some bloodletting. But wait — on the last day of the conference, new data will be presented. Whose ideas about the universe will be confirmed? (No, I'm not going to tell you how it came out! Why ruin Overbye's story?)

Lonely Hearts is about a scientific revolution that is still in progress and more important, the people behind the revolution. You have seen the newspaper headlines and followed the development, and rejection, of new ideas in monthly magazines. Now read the entire story. You won't be disappointed.
— *John Dvorak*

Observing

Totality: Eclipses of the Sun, by Mark Littmann and Ken Wilcox, (University of Hawaii Press, 1991), ISBN 0-8248-1371-5, 224 pages, acid-free paper, $14.95.

The excellent timing of this book is probably no accident! *Totality* is a detailed guide to solar eclipses and how to observe and photograph them. Thirteen chapters describe in a relaxed way what goes on, what to look for, and what you can do to enjoy it more. The last chapter gives many specifics about the July 11 event for viewers in both Hawaii and Mexico.

Visual Astronomy of the Deep Sky, Roger N. Clark, (Cambridge University Press, 1991), ISBN 0-521-36155-9, 355 pages, hardcover, sewn binding, $39.50.

This book is different from nearly all other deep-sky observing manuals. Before it presents an album of things to see, it spends two chapters exploring in detail how the human eye works (both dark-adapted and normally) and how it relates to the view through a telescope. These are important topics that many observers pay scant attention to. The bulk of the book is an album of deep-sky objects, with a photo and a sketch presented side-by-side on a page or spread. Several paragraphs of text (typically) accompany the images, explaining the observational history of the object, what it is astrophysically, and what it looks like.

The book closes with five appendices which give such information as calibrated magnitudes for open clusters (to check your personal vision threshold), BASIC programs for determining air mass and extinction, and a 611-item list of the best deep-sky objects. ☐

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Meetings & Events

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Astronomical Society of the Pacific national meeting, University of Wyoming, Laramie, Wyoming. Contact: Astronomical Society of the Pacific, Wyoming Meeting Information, 390 Ashton Avenue, San Francisco, CA 94112.

July 8-12
Association of Lunar and Planetary Observers Convention, La Paz, Baja California Sur, Mexico. Contact: A.L.P.O., P. O. Box 143, Heber Springs, AR 72543. Phone (501) 362-7624.

July 8-12
Research Amateur Astronomy Symposium, La Paz, Baja California Sur, Mexico. Contact: Corporation for Research Amateur Astronomy, P. O. Box 16542, San Francisco, CA 94116.

July 12-13
Rocky Mountain Star Stare, Badger Flats, Colorado. Sponsored by the Colorado Springs Astronomical Society. Contact: Jim Lawrence, P. O. Box 62022, Colorado Springs, CO 80962. Phone: (719) 593-0801.

July 13
Tidewater Star Party, Tidewater Community College, Portsmouth, Virginia. Contact: Aubrey Hartman, Tidewater Community College Astronomical Society, Physics Department, State Route 135, Portsmouth, VA 23703. Phone: (804) 484-2121 x 235 (days), (804) 488-4354 (evenings).

July 19-20
Gateway to the Universe Star Party, Ontario. Sponsored by the North Bay Astronomy Club. Contact: Merlin Clayton, 50 Van Horne Cres., North Bay, Ontario, Canada P1A 3L3. Phone: (705) 472-1182.

August 7-9
45th Annual Astronomical League National Convention, University of Massachusetts, Amherst. Hosted by the Amateur Telescope Makers of Boston. Contact: John Reed, 1437 Massachusetts Avenue, Lexington, MA 02173.

August 7-11
Mount Kobau Star Party, near Osoyoos, British Columbia. Contact: Peter Kuzel, 4100 25th Avenue, Vernon, British Columbia, Canada V1T 1P4. Phone: (604) 545-1226.

August 9-10
Astronomical League Northwest Regional Convention, near Ellensburg, Washington. Contact: Thom Jenkins, 3312 South Pittsburgh, Spokane, WA 99203. Phone: (509) 838-1381.

August 9-10
Stellafane, Springfield, Vermont. Contact: Stellafane, 60 Victoria Road, Sudbury, MA 01776.

August 9-11
Boise Astronomical Society Star Party, Bruneau Sand Dunes State Park, Mountain Home, Idaho. Contact: Boise Astronomical Society, Inc., P. O. Box 8386, Boise, ID 83707.

August 9-11
4th Convention of Observers of the Latin-American League of Astronomy, Santa Fe, Argentina. Contact: Jorge R. Coghlan, Secretario del Centro Observadores del Espacio, calle San Jerónimo

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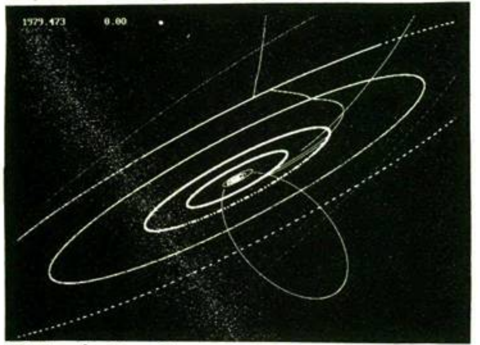

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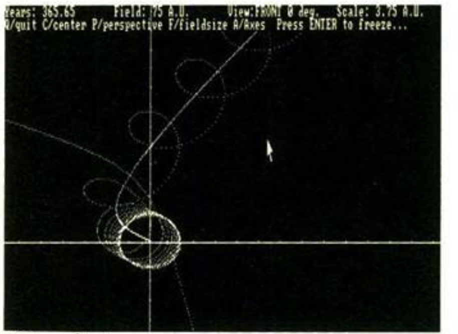

```
Years: 365.65        Field: 75 A.U.        View:FRONT 0 deg.    Scale: 3.75 A.U.
Q/quit C/center P/perspective F/fieldsize A/Axes  Press ENTER to freeze...
```

☐ **Gravitator**™ - Calculates gravitational forces on astronomical bodies such as stars & planets & determines their orbits. See paths plotted & vary scale of view, orientation & angle of view. Input any set of initial conditions, use examples provided or get random sets of clusters. Save systems created to run later or try new conditions. Vary time factor to speed up or slow down simulation. Manual explains theory & use. IBM & compat., CGA or Hercules graphics **$39.95**

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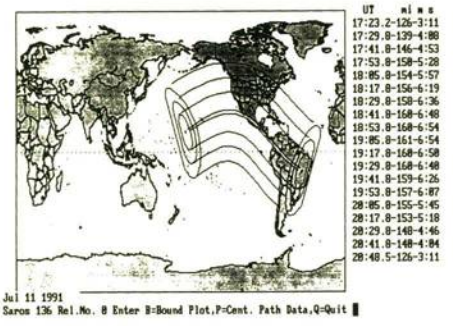

```
UT      mi m s
17:23.2-126-3:11
17:29.0-139-4:00
17:41.0-146-4:53
17:53.0-150-5:28
18:05.0-154-5:57
18:17.0-156-6:19
18:29.0-158-6:36
18:41.0-160-6:48
18:53.0-160-6:54
19:05.0-161-6:54
19:17.0-160-6:50
19:29.0-160-6:40
19:41.0-159-6:26
19:53.0-157-6:07
20:05.0-155-5:45
20:17.0-153-5:18
20:29.0-148-4:46
20:41.0-140-4:04
20:48.5-126-3:11

Jul 11 1991
Saros 136 Rel.No. 0 Enter B=Bound Plot,P=Cent. Path Data,Q=Quit
```

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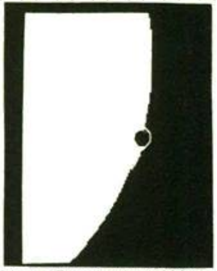
Orion the Hunter



Venus Transit 7/11/5900AD

☐ **LodeStar**™ **2.1**- Get accurate, variable size views of the sky for any date & time from 9999BC to 9999AD for any location on Earth. Includes over 9,000 stars(all naked eye and some to mag. 7.8), Messier objects & Sun, Moon & all planets. Investigate past, present and future with LodeStar! Choose any size view from 180 deg. to 0.18 deg., with or w/o constellation lines. Set limiting mag., option for colored stars & size proportional to magnitude. Sun, Moon & planets show actual size & phase at high magnificatons. See solar eclipses, planetary conjunctions, occultations, transits, etc. Scroll to any object to recenter display or zoom in or out. Use target to identify stars or objects & get RA/Dec, Alt/Az, Rise/Set & transit times. Calculates refraction, precession, parallax. Use Gregorian & Julian calendars. Get printout of displays for field reference or use at your desk.

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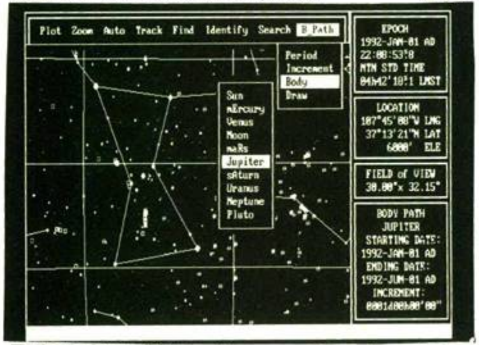

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Mountain Astronomers' Rendezvous and Star Party, Battlement Mesa, Colorado. Sponsored by the Denver Astronomical Society. Contact: Dave Trott, P. O. Box 10814, Denver, CO 80210. Phone: (303) 871-5172.

August 9-11
Starfest '91, Riverplace Campground, Mount Forest, Ontario. Sponsored by the North York Astronomical Association. Contact: Andreas Gada, 26 Chryessa Avenue, Toronto, Ontario, Canada M6N 4T5. Phone: (416) 761-1798.

August 9-11
21st Annual NFCAAA Summer Seminar, Darling Hill Observatory, Vesper, Dakota Astronomical Society. Contact: John Wetsch, P. O. Box 2539, Bismarck, ND 58502. Phone: (701) 256-3620 (evenings).

August 10
Prairie Astronomy Club Star Party, Hyde Observatory, Lincoln, Nebraska. Sponsored by the Prairie Astronomy Club. Contact: Lee Thomas, P. O. Box 80553, Lincoln, NE 68501. Phone: (402) 483-5639.

August 10-11
Dakota Star Watch, Killdeer Mountains, North Dakota. Sponsored by the Dakota Astronomical Society. Contact: John Wetsch, P. O. Box 2539, Bismarck, ND 58502. Phone: (701) 256-3620 (evenings).

August 16-18
5th Annual Alberta Star Party, Waterton Homestead Campground, near Waterton Lakes International Peace Park. Contact: R.A.S.C., Calgary Centre, P. O. Box 2100, Station M, Calgary, Alberta, Canada T2P 2M5. Phone: Rick Ponomar, (403) 381-1332.

August 16-18
Northwoods Starfest, Hobbs Observatory Center, Beaver Creek Reserve, Wisconsin. Sponsored by the Chippewa Falls Astronomical Society. Contact: Bob Elliot, Hobbs Observatory, Route 2, Box 94, Fall Creek, WI 54742. Phone: (715) 877-2787.

August 16-19
2nd Annual Southern Michigan Universal Regional Festival of Stargazers, near Clare, Michigan. Sponsored by the

Genesee Astronomical Society. Contact: Richard Walker, 1220 Merkle Street, Ortonville, MI 48462. Phone: (313) 627-9524.

August 23-25
5th Annual Astronomy Rendezvous and Conference, Normal, Illinois. Sponsored by the Twin City Amateur Astronomers. Contact: Sharon MacDonald, P. O. Box 755, Normal, IL 61761. Phone: (309) 827-4885 (evenings).

August 30 - September 1
Nova East '91, Fundy National Park, New Brunswick, Canada. Contact: Douglas Pitcairn, 13 Ferguson Road, Dartmouth, Nova Scotia, Canada B3A 4J8.

August 30 - September 2
The Conjunction, Northfield Mountain Environmental Center, Northfield, Massachusetts. Contact: Richard Sanderson, P. O. Box 54, Monson, MA 01057.

September 6-8
Astrofest '91, Camp Shaw-Waw-Nas-See 4-H Camp, Kankakee, Illinois. Sponsored by the Chicago Astronomical Society. Contact: Astrofest, P. O. Box 596, Tinley Park, IL 60477.

September 6-8
Astronomy Weekend, Blackwater Falls State Park, Davis, West Virginia. Sponsored by the West Virginia Division of Parks and Recreation and the Kanawha Valley Astronomical Society. Contact: Pat Northeimer, Box 490, Davis, WV 26260. Phone: (800) 225-5982.

September 6-8
Oregon Star Party and Campout, Steens Mountain, Oregon. Sponsored by the Rose City Astronomers. Contact: Oregon Star Party, Oregon Museum of Science and Industry, 4015 SW Canyon Road, Portland, OR 97221.

September 7, October 5
7th Annual Blue Ridge Parkway Regional Stargaze, Julian Price Park, near Blowing Rock, North Carolina. Contact: Greg Kirby, Route 3, Box 472, Granite Falls, NC 28630. Phone: (704) 396-7656. □

Please submit announcements at least four months before the date of the meeting or event.

When you write to organizations listed in Meetings and Events, include a self-addressed, legal-sized envelope with your request for information.

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Best Sellers From the Orion® Catalog

Below are the Orion products from our most recent catalog in greatest demand by serious astronomers and astrophotographers.

Remember: This is Only a Fraction of All the Products Found in Our Catalog.

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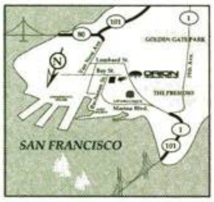

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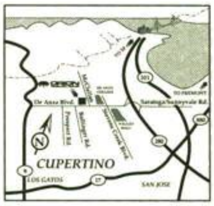

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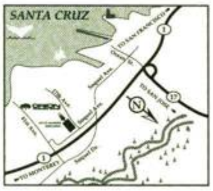
10555 S. DeAnza Blvd., at McClellan
From Hwy 280 take Cupertino exit, south 1.5 miles on DeAnza, from Los Gatos take Hwy 9 to Saratoga-Sunnyvale Rd.
408/255-8770

Monterey Bay/Santa Cruz
2450 17th Ave., West Marine Building,
From Hwy 1, take Soquel Drive exit,
1/2 block from the freeway at Soquel Avenue
408/464-0465



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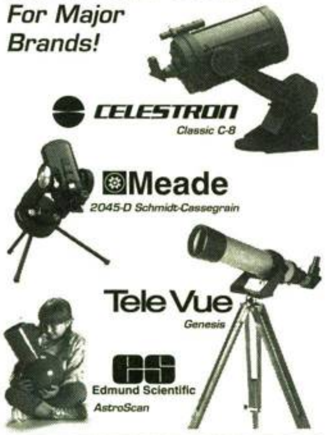


Orion® SpaceProbe™ 4.5" Equatorial Reflector

Our affordable reflector for the advanced student of astronomy. 4.5" f/8 reflector gathers 3.6 times more light than 60mm telescopes; twice as much as 80mm models; features a 900 mm focal length and rack-and-pinion focuser. Full featured equatorial mount with slow motion controls & setting circles. Achromatic 6x30 right angle finder and two eyepieces: 25mm (36x) and 9mm (100x). Deluxe hardwood tripod and accessory tray. Compare our price!

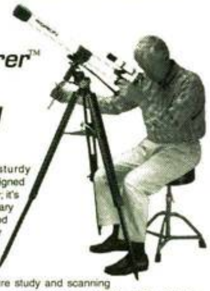
#9097 **$399** (18.73)

Orion® Sky Explorer 80 Equatorial Refractor

77% more light gathering power than 60mm models • 2-element achromatic 80mm objective lens with 1200mm of focal length (f/15) • two Kellner .965" eyepieces: 9mm (133x) and 25mm (48x) • 6x30 achromatic finderscope with adjustable mounting bracket • rack-and-pinion focuser • right-angle star diagonal prism for night • image-erecting porro prism for day • 2x barlow lens • solar image projection screen • special moon filter • piggyback camera mount • 2-section hardwood deluxe tripod • large equatorial mount.

#9098 **$499** (19.43)

Orion® Sky Explorer™ 60 Equatorial Refractor



The Sky Explorer's sturdy equatorial mounting is designed specifically for astronomy; it's ideal for lunar and planetary study, while providing good views of nebulas, star clusters, and double stars. By day, it's a powerful terrestrial telescope, great for nature study and scanning distant vistas. It features a 900mm focal length, MgF_2 coated objective lens; 6x30 achromatic crosshair finderscope; rack-and-pinion focuser, fully coated right-angle star diagonal prism; two quality fully coated Kellner eyepieces, 25mm (36x) and 9mm (100x); all metal equatorial mounting; worm gear slow-motion control knobs, celestial coordinate setting circles; dual flexible control cables; adjustable counterweight; adjustable deluxe hardwood tripod; and lighted accessory tray.

#9092 **$329** (12.70)

Orion® Big Eye™ 8x50 & 11x80 Finder Scopes

You might spend more time viewing through the finder than through your main telescope! Big Eye Scope is Ideal for upgrading any telescope including Schmidt-Cassegrains. Available non-illuminated or with wireless, adjustable, battery-operated illuminated reticle and Polaris grid for accurate polar alignment. With 90° diagonal prisms. Optional deluxe dual-ring brackets are perfect for 8" and 10" Celestron or Meade; will fit many others, too.

8x50 Models The 50mm objectives gather 2.7 times more light than 30mm finders!

8x50 Standard Finder #7100 **$89.95** (3.31)

8x50 Illuminated Finder #7135 **$134.95** (3.56)

Bracket— For 50 mm #5143 **$25.95** (1.89)

11x80 Models These huge finders gulp in over 7 times the light of 30mm finders; 2.5 times more than 50mm models!

11x80 Standard Finder#7146 **$219** (4.16)

11x80 Illuminated Finder #7143 **$269** (4.16)

Bracket— For 80 mm #5140 **$37.95** (2.39)

Superior Performance 7x50 Adlerblick Binoculars

Incredible wide field eyepiece design, Fully Multi-Coated, BAK-4 prisms, and best special glass objective lenses make the 7x50 Adlerblick the arch rival of European brand binoculars selling for 3-4 times the price. Orion buys direct, saving you money. Includes deluxe hard case, lens caps and straps.

#9612 **$269** (4.16)

Orion® 10x70 Fully Multi-Coated Enhanced Giant Binoculars

The standard for hand-holdable astronomy binoculars • 33% lighter—weighs only 58 oz.—yet the same brightness and 7mm exit pupil as our 11x80 MC model • Superior 'BCF' body design • Includes: soft rubber eyecaps, tripod mounting adapter, durable hard carrying case, lens caps and straps.

#9501 **$279** (5.87)

Orion® Enhanced™ Giant Binoculars

20% more light transmission than ordinary "fully coated" binoculars. Fully Multi-Coated optics and superior BAK-4 prisms provide fantastic contrast and greatly improved edge sharpness.

11x80 MC- Brightest, widest-field available. Ideal for deep-space observation under dark skies. Hand-holdable.

#9502 **$349** (6.43)

16x80 MC- 45% higher power, excellent for astronomy and daytime observation. Tripod recommended.

#9496 **$379** (6.43)

20x80 MC- Highest power model perfect for smaller deep-space objects and long range daytime views. Tripod required.

#9498 **$389** (6.43)

Orion® Sky Explorer™ Mini Deep Sky 8x56 Binoculars

56mm objective lenses gather over 2.5 x the light of ordinary 7x35 binoculars. Perfect for viewing faint celestial objects, daytime viewing. Best Multi-Coated BAK-4 optics. 6° field of view. Weighs 33 oz.

#9504 **$139** (4.16)

Orion® Little Giant™ 9x63 Roof Prism Binoculars

Popular mid-sized binocular, Fully Multi-Coated and remarkably lightweight. Excellent contrast and sharpness at center of field, with enough power to see lunar craters & Jupiter's moons. 5.5° field of view. Weight 34 oz.

#9500 **$199** (4.80)

Orion® 7x50 Observer™ Binoculars

Our new Observer binocular is an ideal moderately priced night-vision binocular for both astronomy and general purpose daytime observation. Fully coated optics with a 7° field of view, and a bright 7mm exit pupil. Rugged ribbed rubber covering for a good grip.

#9620 **$84.95** (3.66)

StereoScope™ Binocular Viewing Expander

Open up a new dimension in observation! The stereo effect of this viewer is astonishing. Viewing is more comfortable and it shows more detail, especially of the moon and planets. Specially built for astronomical telescopes, features a fully adjustable 55-75mm interpupillary distance scale and a highly precisce beam splitter which maximizes transmission of light to each eyepiece and equalizes the brightness of each image. Threads securely onto any Celestron or Meade Schmidt-Cassegrain. Includes a thread-on matched 2x Barlow lens. (Shown with two eyepieces, not included.)

#9720 **$399** (3.79)

Orion® 12.5mm Plössl Illuminated Reticle Eyepiece

This new 12.5mm 4-element Plössl offers unprecidented eye relief and observing comfort during long astrophoto exposures. The battery operated integral illuminator has fully adjustable brightness. Features double crossline reticle.

#8484 **$99** (2.79)

World's Finest Illuminated Reticle Eyepiece

6mm Orthoscopic design for required high-power guiding, plus unique X-Y adjustable reticle positioning for easy guide-star alignment. Wireless LED illuminator has adjustable brightness.

#8487 **$139** (2.79)

Orion® 9mm Orthoscopic Illuminated Reticle Eyepiece

9mm Orthoscopic eyepiece with wireless adjustable brightness illuminator. Bull's-eye within three concentric circles helps measure limits of acceptable guiding error.

#8488 **$119** (2.79)

Orion® 12mm Kellner Illuminated Reticle Eyepiece

12mm Kellner eyepiece with cable plugs into LX/3, LX/5 and Premier drive bases, and most drive correctors with illuminated reticle output for polar alignment and guiding.

#8482 **$69.95** (2.59)

Orion® 2" Barlow Lens

2x magnification, Multi-Coated, 2-element 40mm diameter achromatic lens. Baffled to eliminate off-axis glare. Works with all 2" barrel diameter eyepieces. Chrome plated brass barrel and blackened aluminum body with knurled set screw.

#8720 **$69.95** (2.59)

Orion® VariPower™ 2-3x Multi-Coated Barlow Lens

Our best barlow fills the gaps in your eyepiece collection • Internal lens cell slides easily to adjust magnification • Quality optics provide excellent sharpness, contrast and brightness • Works with 1.25" diameter eyepieces and right-angle diagonals.

#8748 **$69.95** (2.59)

Orion® 3-Element Fully Multi-Coated Barlow Lens

Fully Multi-Coated 3-Element Barlow lens provides superior imaging with precise color correction at three wavelengths. For maximum light transmission and highest contrast, we have used the finest quality multi-coating on each air to glass surface. 1.25" diameter.

#8750 **$59.95** (2.59)

Orion® Deluxe Fully-Baffled Multi-Coated Barlow Lens

Fully internally opaqued and baffled to block stray light for noticeably higher contrast. Large 27mm multi-coated 2-element lens provides 2x magnification with any 1.25" eyepiece.

#8746 **$49.95** (2.39)

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If you are not completely satisfied with your purchase from Orion, for any reason, just return it in new condition within 30 days after delivery for a full refund.

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77° Field UltraScan Wide-Angle Eyepieces

Unlimited visibility is yours with up to 77 degrees of field to catch your eye. High quality optical materials and superb coatings, for the ultimate in contrast and resolution.

1.25" UltraScan Eyepieces
Five optical elements utilizing the latest high refractive-index optical glass materials achieve extremely wide fields with fewer elements than many competitive eyepieces, reducing weight and cost. Each lens surface is fully Multi-Coated, for the ultimate in contrast and elimination of stray reflections. Integral rubber eyeguards.

9mm-#8420 **$99** (2.79), ***12mm***-#8421 **$109** (2.79)

15mm-#8422 **$129** (2.79), ***19mm***-#8423 **$139** (2.79)

2" UltraScan Eyepieces
These incredible oculars provide breathtaking panoramic, bright views that will astonish you!

30mm 2" UltraScan Eyepiece–This 5-element, 77 degree field UltraScan eyepiece combines the widest possible apparent and true fields with a larger image scale than our 40mm.

#8424 **$199** (2.79)

40mm 2" UltraScan Eyepiece - Orion's brightest, widest true-field UltraScan eyepiece utilizes a sophisticated 7-element design, providing a 68 degree apparent field; the widest we could fit into the 2" diameter barrel. #8425 **$179** (2.79)

High Resolution Orion® Ultrascopic Eyepieces

Unlike other premium eyepieces, Orion Ultrascopics offer complete multi-layer coatings on ALL surfaces, for superior light transmission and contrast. Modern 5- and 7- element designs for pinpoint star images and breathtaking detail. Wide 52° field of view. Compare with other brands selling for much more!

Wide Field 5-element

35mm #8560 **$89.95** (2.59)

30mm #8562 **$79.95** (2.59)

25mm #8564 **$64.95** (2.59)

Medium-High Power 5-element
20mm #8566, 15mm #8568, 10mm #8570, 7.5mm #8572

$59.95 ea. (2.59)

High-Power 7-element 5mm #8574, 3.8mm #8576

$79.95 ea. (2.59)

Orion® MegaVista™ 1.25" Wide Angle Eyepieces

Incredible Fully Multi-Coated high-transmission 7-element eyepieces with integral rubber eyeguard and long eye-relief.

10.5mm- An incredible 67° field for outstanding planetary or deep space performance.

#8552 **$109** (2.79)

16.8mm- Outstanding high-contrast eyepiece with stunning 70° field ideal for deep space.

#8554 **$119** (2.79)

Orion® UltraZoom™ 7-21mm 1.25" Eyepiece

The finest zoom you can buy for your 1.25" telescope. An excellent choice for astronomy or terrestrial observing. 65°-35° field.

#8556 **$129** (2.79)

Orion® Explorer Series 1.25" Eyepieces

Remarkably affordable, Multi-Coated parfocal eyepieces with great performance. Each carefully selected series has been chosen to provide a sensible progression of magnifications. Threaded for filters. Internally blackened to prevent stray light reflections.

Kellner Eyepieces-
6mm #8536, 9mm #8538, 12mm #8540, 18mm #8508, 25mm #8510, 40mm #8512

$33.95 ea. (2.19)

Orthoscopic Eyepieces-5mm #8500, 7mm #8502, 9mm #8504, 12.5mm #8506, 18mm #8524, 25mm #8526

$46.95 ea. (2.19)

Orion® Explorer Series .965" Eyepieces

Get the most from your small telescope with these fine Multi-Coated eyepieces. Standard .965" barrels fit all Japanese standard small telescopes.

.965" Orthoscopic Eyepieces-
5mm #8580, 7mm #8581
9mm #8582, 12.5mm #8583

$37.95 ea. (2.19)

.965" Kellner Eyepieces
18mm #8584, 25mm #8585

.965" Achromatic Huygenian Eyepieces- 40mm #8586

$24.95 ea. (2.11)

Orion® SkyGlow™ Enhanced Light Pollution Filters

Enhance your viewing of faint deep sky objects with the best broadband light pollution filter you can buy. Our SkyGlow absorbs frequencies emitted by city lights, allowing transmission of the rest of the visible spectrum, yielding dramatic results.

SkyGlow Broadband Filters- Photographic and Visual
For use in slight to moderately light polluted areas.

1.25" Broadband Filter–fits 1.25" eyepieces.

#5660 **$59.95** (2.59)

Schmidt-Cassegrain Broadband Filter–fits rear cell of Meade & Celestron SC scopes. #5658 **$79.95** (2.59)

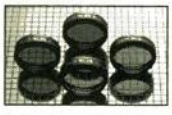
52mm Broadband Filter–For 52mm camera lenses, adapter rings available for other diameters. #5668 **$66.50** (2.59)

SkyGlow UltraBlock Filters–Visual Only
For severely light polluted areas and faint nebulae.

1.25" UltraBlock Filter–
fits 1.25" eyepieces. #5654 **$79.50** (2.59)

Schmidt-Cassegrain UltraBlock Filter–fits rear cell of Meade & Celestron SC scopes. #5656 **$99.00** (2.59)

Orion® Color Filters for Eyepieces



Solar system observations are dramatically improved by Orion colored filters. For visual use, thread one into the barrel of any standard eyepiece. For planetary and lunar photography, Schmidt-Cassegrain owners can attach the filter to the eyepiece inside the tele-extender. Can also be threaded directly into a universal camera adapter.

Basic Set of 4 Filters .965"- Includes #80A Blue, #58 Green, #25 Red, #15 Yellow.

#5510 **$29.95** (2.19)

Basic Set of 4 Filters 1.25"- Includes #80A Blue, #58 Green, #25 Red, #15 Yellow.

#5514 **$39.95** (2.19)

Expansion Set of 4 Filters 1.25"- Includes #21 Orange, #47 Violet, #11 Yellow-Green, #82A Very Pale Blue.

#5516 **$39.95** (2.19)

Deluxe Set of 8 Filters 1.25"- Includes all the filters in our basic and expansion filter sets.

#5517 **$74.95** (2.79)

Individual 1.25" Filters- #80A Blue (#11040), #58 Green (#5540), #25 Red (#5536), #15 Yellow (#5532), #21 Orange (#5534), #47 Violet (#5538), #11 Light Yellow-Green (#5530), #82A Very Pale Blue (#5544)

$11.95 ea. (.99)

Moon Filters

Cuts 87% of the light from the Moon. Reduces glare by uniformly reducing light transmitted over the entire spectrum.

.965" #5664 **$14.95** (2.11)

1.25" #5662 **$14.95** (2.11)

Breakthrough Low-Price Plössl Eyepieces!

These new Multi-Coated Plössl eyepieces are incredibly low priced! Good quality optics for sharp, clear images. Precision four-element Plössl lens elements mounted in sturdy aluminum barrels. Available in 12mm, 18mm, or 25mm focal lengths, with 1.25" barrels. Buy all three for less than some single eyepieces!

12mm-#8596
18mm-#8597
25mm-#8598 **$39.95 ea.** (2.39)

Deluxe Eyepiece Case

Organize and protect your valuable eyepieces and other accessories. This durable case with double hinges holds up to 10 eyepieces plus barlow. Die cut foam insert for snug secure fit. O.D. 8-1/2"x12-1/2"x3-1/8".

#5913 **$17.95** (2.49)

Deluxe Metal-Clad Accessory Cases

Keep accessories and camera safe and clean. Diced foam inserts can be tailored to your needs. Sturdy handle, two latches, key.

Regular Case: 16"x12"x6 1/2" #5920 **$49.95** (5.09)

Large Case: 19 1/2"x12"x6 1/2" #5921 **$69.95** (5.92)

Deluxe Field Tripod Tote Bag

Designed for the field tripod with padded insert to separate wedge from tripod during transportation. Specifically made for wedge combinations of Schmidt-Cassegrain telescopes up to 10" aperture. Allows storage without changing polar alignment. This blue bag is made of tear, rip and mildew resistant 100% Cordura nylon.

#15096 **$79.95** (4.65)

Orion FlexiShield™ Dew Caps

Eliminate dew problems with FlexiShield! Better performance, more rugged, and easier storage than rigid dew caps. Forms into a tube with the velcro closure, opens flat for easy storage and transportation. Fits your telescope tube snugly, with wide rubber padding and full-length velcro closure—needs no screws. Models to fit most telescopes.

90mm Celestron/Meade Spotting Scopes	#4203	**$24.95** (2.39)
90mm Celestron Rubber Armored Spotting Scopes	#4205	**$24.95** (2.39)
4" Meade Schmidt-Cassegrain	#4204	**$24.95** (2.39)
8" Celestron/Meade Schmidt-Cassegrains	#4200	**$39.95** (2.39)
10" Meade Schmidt-Cassegrains	#4201	**$49.95** (2.39)
11" Celestron Schmidt-Cassegrains	#4202	**$59.95** (2.39)

Orion® Dew Zapper

Orion's Dew Zapper is a sure-fire cure for dew problems on your 8" or 10" Celestron or Meade Schmidt-Cassegrain telescope. Dew Zapper gently replaces lost heat, bringing the corrector plate temperature slightly above air temperature.

8" Dew Zappers- fit all Meade & Celestron 8" Schmidt-Cassegrains

DC Model #3503, AC Model #3504 **$39.95** (2.39)

10" Dew Zappers- fit all Meade 10" Schmidt-Cassegrains

DC Model #3506, AC Model #3508 **$39.95** (2.39)

Dew Remover Gun

Moisture that interferes with viewing dissipates quickly with this 12V DC, 156 watt warm air gun. Has 4-1/2' cord.

#5601 **$17.95** (2.48)

Orion® Slow-Motion Adapter

Attaches to your tripod pan head and gives you two slow-motion control knobs to make precision adjustments in altitude and altazimuth. Very handy for tracking planets, the moon, etc. with refractor teleiscopes and small spotting scopes. Attaches to any camera tripod with a standard 1/4-20 thread.

#7012 **$49.95** (2.59)

Orion® Dual Balance System

Unlike ordinary counter-weights, our system allows instant adjustment in both directions. Easily balances your scope to offset both piggyback loads or rear-cell cameras, 2" diagonals, and other accessories. Rigid, precision machined dovetail bar mounts to telescope in existing accessory holes.

For Meade SC 8"	#5150	**$74.95** (4.65)
For Celestron 8" C-8	#5149	**$79.95** (4.65)
For Meade SC 10"	#5152	**$84.95** (4.65)

Starlite Red LED Flashlight

The Starlite is the only adjustable-brightness night-vision red flashlight. Lifetime solid-state LED can't burn out. Extra efficient electronic circuit for long battery life. Uses one 9-volt battery (not included).

#5714 **$24.95** (2.11)

Astronomer's Flashlight

Indispensable and indestructible. Has special night-vision red filter and a diffusion lens for even illumination. An essential addition to your astronomy accessories. Requires 2 D-cell batteries (not included).

#5701 **$9.95** (1.89)

Rechargeable Battery Porta-Pack

12 Amp Hour Porta Pac
Ideal for operating your telescope plus higher power-consuming accessories such as an Orion Dew Zapper. Battery is encased in high-impact polystyrene. Carrying case of Cordura nylon with shoulder strap and handle. Wt. 10 lbs.

#2354 **$99 ea.** (6.23)

Popular Observer's Chairs

Make observing more comfortable and enjoyable with one of these great chairs.

Standard Model-
Has adjustable-height center column and padded vinyl seat. Folds for easy storage.

#5935 **$39.95** (3.96)

Deluxe Model-
Is much heavier-duty, built for professional musicians. Extra thick padding, wide footprint. Adjustable and disassembles for storage.

#5934 **$89.95** (5.65)

Orion® UltraGuider™

Advanced features most requested by advanced deep-space astrophotographers at a low price • Use with your Meade or Celestron Schmidt-Cassegrain telescope • Easily adjustable prism allows wider choice of guide stars • Ultra-precise helical focus of your eyepiece • Adjustable camera focal plane position

#5139 **$119** (2.79)

Orion® Premium Off-Axis Guider

Multi-Coated for Peak Performance! • Low Orion price for our popular, precision anodized guider

#5144 **$59.95** (2.59)

Rack & Pinion Focusers

These top quality focusers are designed for Newtonian reflectors. Fit any size tubes.

1.25" Focuser
Quality diagonal-cut rack for smooth focusing. Secure slide-fit eyepiece holder. Integral socket for single-stalk diagonal support if desired.

#13017 **$44.95** (2.39)

2" & 1.25" Focuser
Large clear diameter ideal for larger scopes and wide-field optics. Precision diagonal cut rack. Long travel for visual and photographic use. Interchangeable 2" and 1.25" holders with set screws.

#13019 **$69.95** (3.31)

Orion® 45-Degree Erect Image Diagonals

See the world as it really is with Orion's new 45-degree erect image diagonal. Upside-down, backwards and topsy-turvy images can often confuse even the stoutest and most experienced observer. Turn it right-side-up with your choice of three models to select from.

.965 Diagonal	#8759	**$59.50** (2.59)
1-1/4" Diagonal	#8753	**$59.50** (2.59)
Size-Adapting Hybrid Diagonal	#8755	**$59.50** (2.59)

Star Diagonals

1.25" Star Diagonal
Primarily for astronomical use, lets you view at a right angle. Multi-coated, for 1.25" eyepieces.

#8763 **$39.95** (2.39)

.965" Star Diagonal
Same as 1.25" Star Diagonal, but with standard coated optics. Works with .965" eyepieces and eyepiece holders.

#8761 **$24.95** (1.89)

2" Star Diagonal

Get the widest possible field of view from your Schmidt-Cassegrain Telescope. This star diagonal features a special aluminized and overcoated precision first-surface flat mirror.

#8767 **$89.95** (2.89)

Orion® Tele-Extenders

For high powered photography with your Meade, Celestron 4", 8", 10", 11", 14" Schmidt-Cassegrain.

Standard Tele-Extender
Use this Tele-Extender in conjunction with an eyepiece. Attaches to visual back of Meade or Celestron Schmidt-Cassegrain telescopes, and to 35mm camera with T-ring, sold separately.

#5125 **$27.95** (1.89)

Variable Tele-Extender
Uses an adjustable extension tube, allowing magnification to be changed without switching eyepieces. Attaches with T-ring, sold separately.

#5127 **$39.95** (1.89)

Universal Camera Adapters

Standard Universal Camera Adapters
Combination Eyepiece Projection Tube and Prime Focus Adapter for refractors and reflectors with 1.25" eyepiece holders. Use with T-Ring (sold separately) to match your 35mm camera.

.965" #5268 **$29.95** (1.89)

1.25" #5264 **$34.95** (2.39)

Variable Power Camera Adapter

Unique sliding barrel design allows variable projection distances during eyepiece projection photography, eliminating the need to change eyepieces when magnification changes are required.

#5262 **$44.95** (2.39)

Orion® T-Adapter

For prime focus photography. Use with T-ring to match your 35mm camera. For Meade, Celestron 4", 8", 10", 11", 14" SC. Can be used as 2" camera adapter.

#5116 **$27.95** (1.89)

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Readings and Resources

Demise of Dinosaurs (page 30)

"An Extraterrestrial Cause for the Cretaceous-Tertiary Extinction" by L. W. Alvarez, W. Alvarez, F. Asaro, and H. V. Michel, *Science,* vol. 208, pp. 1095-1108, 1980. This was the paper that started it all.

"Extinctions — or, Which Way Did They Go?" by Steven M. Stanley, *Earth,* January 1991. A look at the Cretaceous-Tertiary extinction from the paleontological point of view.

Cosmology (page 38)

Deep Time by David Darling, (Delacorte Press, 1989). Tells the history of a single particle from the Big Bang to the death of the universe — and the far future of the universe isn't likely to resemble what's going on now.

The Big Bang by Joseph Silk, (W. H. Freeman, 1989). Now in its second edition, this is a good outline on early cosmos history aimed at lay readers.

Gamma Ray Observatory (page 44)

The Gamma Ray Observatory, NASA publication NP-124. Gives the low-down on gamma-ray astronomy in general and on GRO, its four instruments, and what it will observe.

"ROSAT's Penetrating X-ray Visions" by Alan Dyer, ASTRONOMY, June 1991. A report on the recently completed ROSAT survey of the x-ray sky, which gives some clues as to what GRO may discover at gamma-ray energies.

When Worlds Align (page 62)

"Travel Tips for the Big Eclipse" by Joel Harris, ASTRONOMY, June 1991. Things you should know for a trouble-free trip to Mexico.

"How to Photograph the Eclipse" by Alan Dyer, ASTRONOMY, April 1991. Instructions for different techniques for capturing the partial and total eclipse phases on film.

Center of the Galaxy (page 74)

Turn Left at Orion, by Guy Consolmagno and Dan M. Davis, (Cambridge, 1990). An introductory romp through the constellations in search of bright deep-sky objects.

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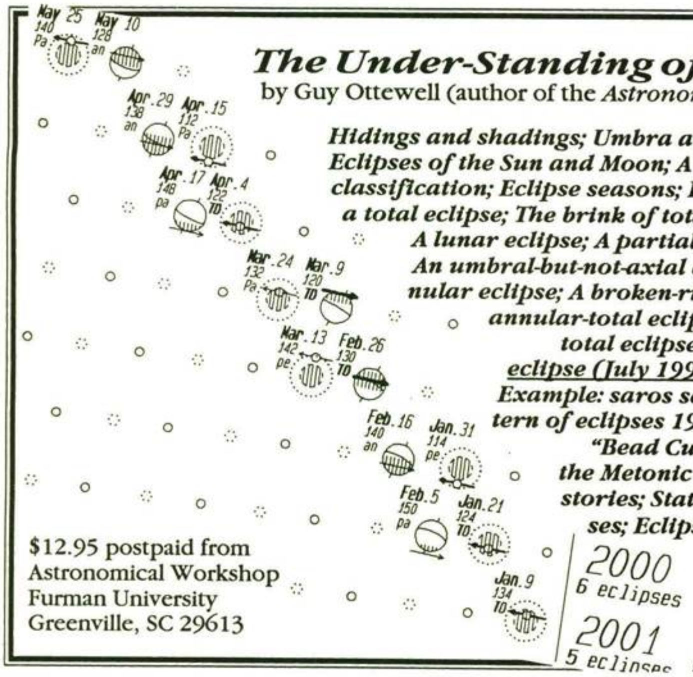

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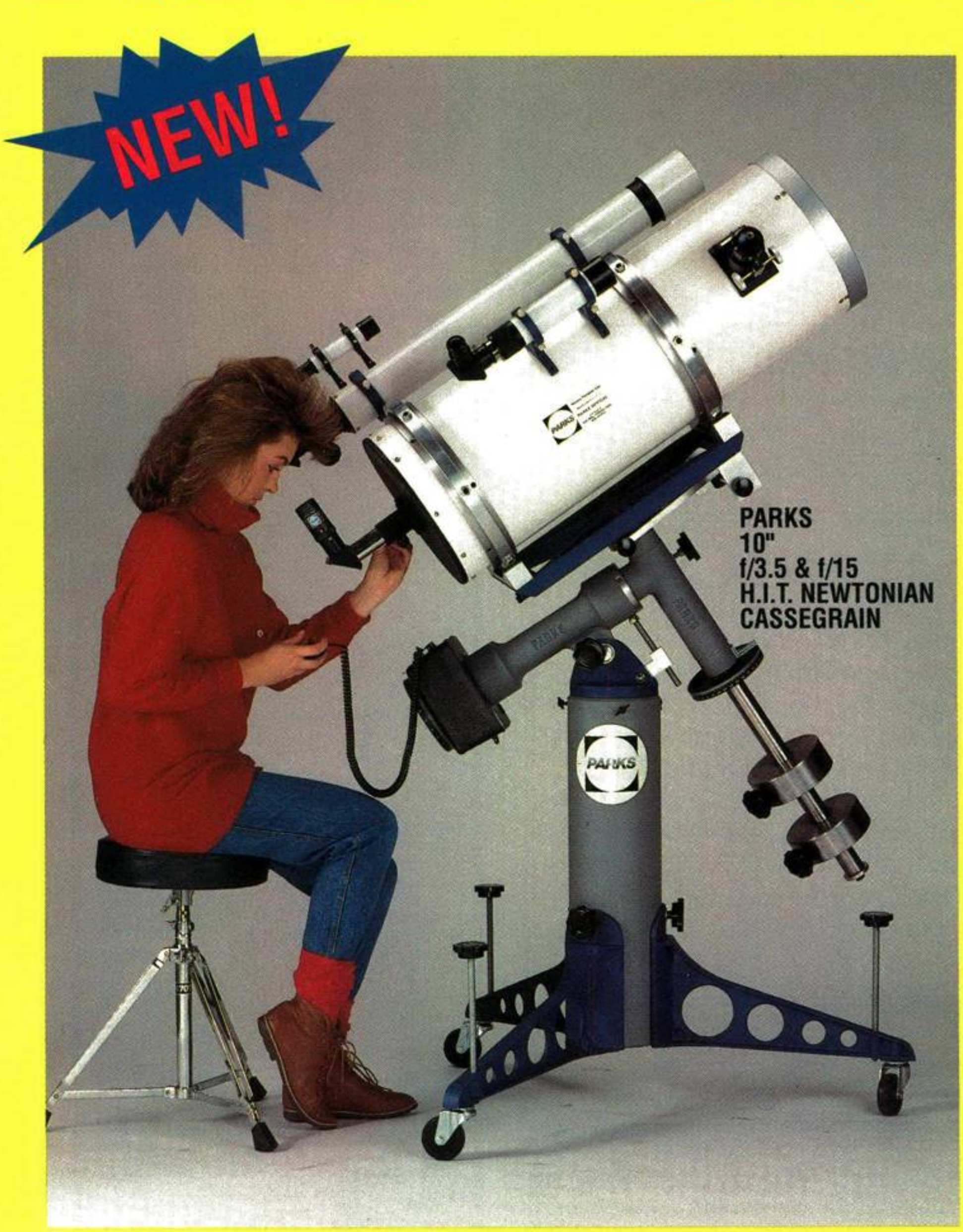

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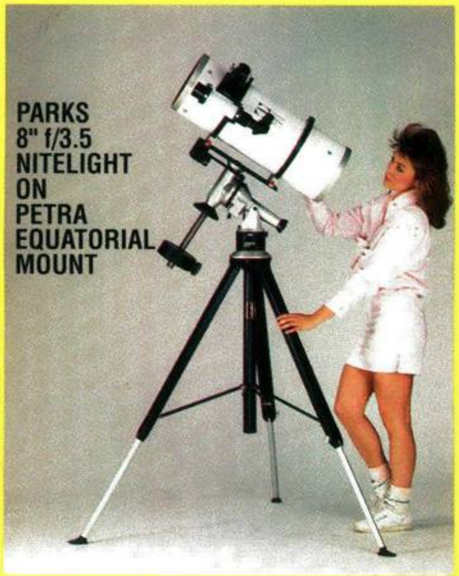

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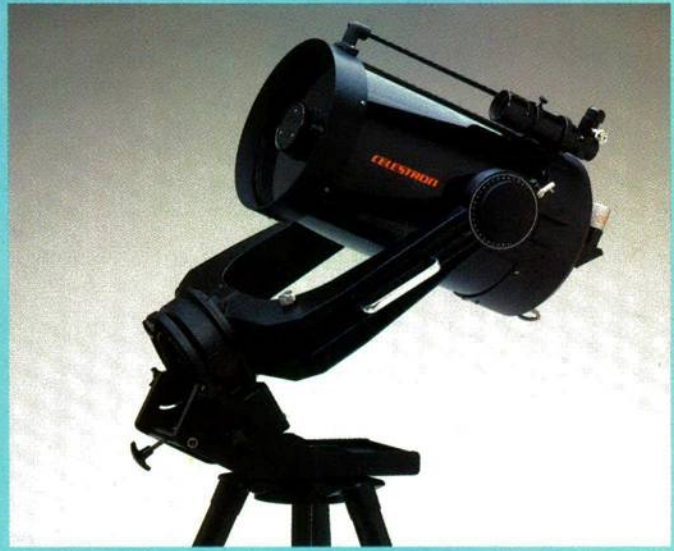

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